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Managing Circular Material Choices in Practice

Trade-offs, Constraints, and Supply Chain Design Impacts

Master's thesis in the Supply Chain Management Programme

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Abstract

Despite growing regulatory pressure and corporate sustainability commitments, circular material adoption in industry remains constrained by operational realities that existing research rarely examines in depth. The transition to a circular economy requires firms to substitute virgin materials with recycled, bio-based, or locally sourced alternatives, yet this transition is not merely a technical or environmental decision. It is a constrained organizational process embedded within existing supply chain structures, cost pressures, and operational requirements. The research investigates how businesses make circular material selection decisions, what trade-offs emerge in the process, and how these decisions influence supply chain design.

Using a qualitative, exploratory research design, semi-structured interviews were conducted with professionals from eleven organizations across diverse industrial sectors, including automotive, steel, MedTech, defense, fashion, and energy. Data were analyzed through thematic analysis using an abductive approach, iteratively linking empirical findings to theoretical frameworks from sustainable supply chain management, circular economy theory, decision-making theory, and the resource-based view.

The findings demonstrate that circular material selection follows a structured, multi-stage decision process in which technical feasibility, safety, and regulatory compliance function as primary gatekeepers, with sustainability considerations entering the evaluation only after operational thresholds are met. Rather than competing equally with other criteria, environmental objectives are integrated conditionally within an already constrained decision space. Significant trade-offs emerge between circularity and cost efficiency, customer requirements, performance reliability, and supply chain risk, managed through cross-functional collaboration, pilot-based implementation, and supplier co-development. Material choices were further found to carry substantial downstream consequences for supply chain structure, driving shifts in supplier networks, reverse logistics integration, geographic sourcing, and traceability requirements.

Taken together, these results reframe circular material selection not as a sustainability decision constrained by operations, but as a fundamentally operational and supply chain design decision within which sustainability must find its place.

Keywords: Circular economy, Circular material selection, Sustainable supply chain management, Supply chain design, Reverse logistics, Sustainability trade-offs.

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1. Introduction

For decades, industrial production has largely followed a linear economic logic commonly summarized as *take, make, and dispose*. This model has enabled economic growth and global industrial expansion but has simultaneously contributed to resource depletion and environmental degradation. At the beginning of 2026, scientists reported that human activities had breached seven of nine planetary boundaries, placing the Earth in a “danger zone” (Stockholm Resilience Center, 2025; Planetary Health Check, 2025). These developments highlight the increasing pressure on natural systems and emphasize the need for new approaches to managing material resources.

Despite growing sustainability initiatives, global resource consumption continues to exceed regenerative capacity. The circularity metric was estimated at 6.9% in 2025 (Circularity Gap Report, 2025), indicating that the vast majority of materials still flow through linear systems. Activities related to material extraction, processing, and disposal account for a substantial share of global greenhouse gas emissions (Ellen MacArthur Foundation, 2024; OECD, 2025b). Consequently, improving the sustainability performance of industrial systems requires addressing material flows rather than focusing solely on energy efficiency or emissions reduction.

The circular economy has emerged as an alternative to the linear model, promoting resource efficiency, reuse, and closed material loops (Geissdoerfer et al., 2017; Kirchherr et al., 2017). Within this paradigm, firms are encouraged to replace virgin materials with recycled, bio-based, or locally sourced alternatives. However, such transitions do not occur solely at the system level. Firms implement through concrete operational decisions, particularly those concerning material selection within supply chains.

While circular economy research frequently conceptualizes the transition as a systemic redesign of industrial production, firms encounter circularity through everyday operational decisions. New materials must coexist with established performance requirements, cost structures, regulatory constraints, and customer expectations (Bocken et al., 2016; Govindan & Hasanagic, 2018). As a result, material selection becomes less a matter of environmental optimization and more a matter of prioritization among competing objectives (Pagell & Shevchenko, 2014). Material choice, therefore, becomes a central operational mechanism through which firms translate circular ambitions into practice.

By 2026, voluntary corporate social responsibility (CSR) activities related to circular material selection have shifted and are now seen as mandatory operational requirements for industrial firms (Yuan, 2025). The primary driver of this transition is the European Union's Ecodesign for Sustainable Products Regulation (ESPR), which took effect in July 2024 and mandates that products sold within the internal market meet rigorous standards for recyclability, reuseability, and durability (Regulation (EU) 2024/1781). This regulation explicitly targets the material level, requiring businesses to substantiate the use of virgin resources when viable recycled alternatives exist (Papile & Del Curto, 2026). For lead firms in the supply chain, the decision-making logic is no longer purely economic; it is now about ensuring legal market access (Paeplow et al., 2026).

A keystone of this regulatory push is the implementation of the Digital Product Passports (DPP). The new system now requires that every industrial component have a digital identity that tracks its material composition, carbon footprint, and recycled content throughout its entire lifecycle (Regulation (EU) 2024/1781; Yuan, 2025). For decision-makers, the DPP acts as a critical information bridge, reducing the uncertainty traditionally associated with secondary materials (Paeplow et al., 2026). Nevertheless, DPP introduces a new layer of complexity by linking material selection directly to data management and legal liability. If a company cannot verify and present the provenance of its materials using these digital passports, it will face fines and, eventually, exclusion from key markets (Paeplow et al., 2026). This regulatory pressure elevates material selection from a localized procurement task to a high-stakes strategic function (Yuan, 2025).

Asymmetric information between actors complicates circular material selection and introduces significant complexity. It differs from traditional linear systems that operate within stable, predictable supply chains sourced from virgin resource extractors. Meanwhile, circular systems exhibit greater stochasticity in the quality, quantity, and timing of secondary materials (Bai et al., 2020). By 2026, the role of digitalization has shifted from a supporting tool to the primary infrastructure of the circular economy, effectively transforming physical waste into a visible, bankable asset class (UNIDO, 2025).

Advanced technologies, such as artificial intelligence and machine learning, are increasingly used to manage uncertainty in reverse logistics and circular supply chains. Rather than merely tracking product flows, these systems can support predictive decision-making by analyzing customer preferences, return reasons, and product-related data to forecast return rates in reverse logistics processes (Adıgüzel Tüylü & Eroğlu, 2019). Such forecasting eases the procurement process, where these tools can help to anticipate the availability of recycled inputs months in advance.

Blockchain technology plays a complementary role by strengthening the traceability and transparency of material provenance in circular supply chains. By creating immutable records of material flows, changes of ownership, and processing steps, blockchain can provide more reliable data on recycled or bio-based materials, thereby facilitating their assessment for high-value industrial reuse. Such traceability can also support businesses in substantiating sustainability claims, reduce the risk of greenwashing, and help them respond to increasing demands for environmental accountability in circular supply chains (Rejeb et al., 2023).

Despite the potential of digital technologies to enable circular economy practices, a gap remains between technological possibilities and organizational implementation. Existing research often remains conceptual or focuses on digital tools and pilot cases. At the same time, the field requires further empirical work on how firms can advance their digital maturity and transform data into actionable knowledge for circular decision-making (Rodriguez Romo et al., 2025). Hence, businesses have refined their decision logic, meaning that material selection is no longer just a physical assessment of the resource but also a verification of the accompanying digital twin. In 2026, adaptation and shifting towards circularity depend heavily on technological capabilities, meaning that if a material's data cannot be verified, the material itself is functionally non-compliant (UNIDO, 2025).

Viewing the industrial landscape of 2026, it is defined by consequential geopolitical volatility. Consequently, the fundamentals of material selection have reformed from procurement assignments to a primary pillar of strategic autonomy. The reliance on long, linear supply chains for critical raw materials, such as rare earth elements, lithium, and high-performance polymers, has put businesses at risk of severe supply disruptions, with export restrictions on these materials increasing fivefold since 2009 (OECD, 2025a). In this market, circularity is no longer viewed solely as a sustainability goal. Now it is more of a strategic defensive move against the weaponization of trade and resource nationalism (Siefridt, 2026).

In addition, businesses prioritize recycled or locally recovered materials to mitigate the risks posed by geopolitical tensions and trade barriers that can affect their operations. This strategic move is intrinsically connected to the forthcoming Circular Economy Act (CEA). Although the formal legislative proposal is scheduled for Q3 of 2026, its expected structure is already imposing a corporate strategy. The act aims to create a unified single market for secondary raw materials, incentivizing firms to treat local waste streams as a neutral geopolitical resource base immune to international trade barriers (Siefridt, 2026; Institute for European Environmental Policy, 2025).

Viewed from a broader perspective, the strategic dimension introduces a practical decision-making logic centered on risk-adjusted costs. Circular materials may currently command a price premium or exhibit technical differences compared to virgin alternatives. Still, they offer superior long-term value by reducing exposure to supply disruptions and geopolitical volatility. As dependence on globally concentrated virgin-material supply chains creates structural vulnerabilities, circular and locally recovered materials increasingly serve as a hedge against supply-chain exposure and raw-material dependency (Carrara et al., 2023). This strategic logic has become increasingly relevant as export restrictions on industrial raw materials have expanded, increasing the risk of supply chain disruption in globally interdependent supply chains (OECD, 2025a). Consequently, in the 2025 market, material costs cannot be assessed solely by spot price; they must also account for the security and resilience of the supply chain that delivers them. Material selection can therefore be understood as a vital tool for industrial resilience, enabling firms to maintain market access and operational stability in an increasingly fragmented global economy (Carrara et al., 2023; OECD, 2025a).

1.1 Background

The circular economy proposes that economic activity should preserve value in products, components, and materials for as long as possible while minimizing waste generation (Ghisellini et al., 2016). Much of the early research has focused on business models, recycling systems, and reverse logistics structures that enable circular flows (Rizos et al., 2016; Farooque et al., 2019). However, the feasibility of these systems ultimately depends on the materials used in products.

Material properties determine durability, reparability, recyclability, and compatibility with existing processing technologies. Consequently, the adoption of circular principles often begins with substituting materials rather than redesigning entire systems. The choice between virgin, recycled, and bio-based inputs influences not only environmental performance but also product functionality, quality, stability, and supply availability. Therefore, material selection represents a critical interface between sustainability ambitions and operational feasibility.

Traditional approaches treat material selection as a technical or environmental consideration. However, changing materials alters sourcing strategies, supplier relationships, inventory planning, and logistics configurations. Circular materials may require new suppliers, localized sourcing, or reverse logistics systems, thereby reshaping the supply chain structure.

Previous studies show that circular supply chains differ from linear ones in terms of uncertainty, coordination needs, and information requirements (Bai et al., 2020). Introducing alternative materials, therefore, affects not only environmental performance but also cost structures and operational stability. As a result, material selection becomes a supply chain design decision rather than an isolated sustainability initiative.

1.2 Problem Statement

The transition to a circular economy has become a strategic necessity for industrial resilience. Firms increasingly seek to integrate recycled or bio-based inputs into existing production systems while maintaining competitiveness. However, a persistent implementation gap remains between circular economy ambitions and operational realities, as firms often struggle to translate the broad concept of circular economy into practical industrial implementation (Bianchini et al., 2019).

The existing literature has extensively examined barriers to adopting the circular economy and has proposed frameworks for closed-loop supply chains (Rizos et al., 2016; Farooque et al., 2019). These perspectives often assume that organizations will implement circular solutions once they can prove technological and economic feasibility. In practice, organizations rarely optimize for circularity directly. Instead, they must balance functional reliability, cost efficiency, regulatory compliance, and customer expectations (Wu & Pagell, 2011; Pagell & Shevchenko, 2014).

Consequently, material selection entails structural trade-offs among environmental performance, operational performance, and economic viability. Rather than being a purely environmental decision, it becomes a negotiation across multiple organizational functions embedded in existing operational structures (Bai et al., 2020).

This lack of understanding of how firms manage these cross-functional trade-offs indicates a critical research gap. Current research explains what circular supply chains require but offers limited insight into how decision-makers evaluate and prioritize circular materials when organizations cannot fully resolve the trade-offs involved (Montabon et al., 2016; Ghisellini et al., 2016). The challenge, therefore, lies not only in developing circular materials or identifying barriers to adoption, but also in understanding the decision logic that governs their acceptance or rejection within firms.

Accordingly, this study adopts a decision-making perspective on circular material selection and examines how such choices reshape supply chain structures.

1.3 Aim

This study aims to investigate how businesses implement circular material selection within their supply chains. Specifically, the study seeks to understand decision-making processes and constraints in material selection, identify trade-offs between operational performance and sustainability, and evaluate how these choices influence supply chain design and business models. By focusing on decision logic rather than adoption outcomes, the study helps explain how circular economy principles translate into operational practice.

1.4 Research Questions

To achieve this objective, the study addresses three interconnected research questions:

1. How are decisions regarding material selection made in circular supply chains (e.g, recycled, locally sourced, or globally sourced materials)?
2. What trade-offs emerge between sustainability objectives, cost efficiency, and customer requirements?
3. In what ways does material selection influence supply chain design?

Together, the research questions move from decision processes to prioritization outcomes and, finally, to structural supply chain implications, explaining how circular ambitions translate into operational reality.

1.5 Delimitations

This study focuses on circular material selection as a decision point in supply chains and on how these decisions influence supply chain design. The scope is limited to organizational decision-making processes within focal firms, particularly those related to procurement, engineering, and sustainability. While the implementation of the circular economy involves multiple supply chain actors, including suppliers, recyclers, and logistics providers, this study primarily examines the perspective of focal firms responsible for material selection decisions.

The study is further limited to circular materials for industrial and technical applications, where material performance, regulatory compliance, and supply chain feasibility are critical decision factors. Broader circular economy strategies, such as product design for circularity, business model innovation, or end-of-life management systems, are not examined in detail, except where directly relevant to material selection decisions.

Additionally, the study focuses on organizational decision-making processes rather than quantitative performance outcomes. The research does not aim to measure environmental impact, cost savings, or operational performance associated with the adoption of circular materials. Instead, the objective is to understand how decision-makers make these decisions and how those decisions influence supply chain design.

Finally, the study is geographically and empirically limited to organizations accessible through the selected case companies and interview participants. Although the sample includes multiple sectors, this thesis interprets the findings in relation to the specific organizational contexts examined rather than aiming to provide statistically generalizable results.

2. Theoretical Background

This chapter presents the theoretical background relevant to the research questions. It introduces key concepts and theories related to circular economy, material selection, trade-offs, and supply chain design. The chapter concludes with the conceptual framework (Figure 1), which illustrates how these theoretical perspectives relate to circular material selection and supply chain transformation.

2.1 Circular Economy and Material Flows

The concept of the circular economy has evolved from an environmental niche to a core element of global industrial transformation. Although finding the ultimate definition of this concept is complex, the literature presents diverse perspectives, ranging from critical ecological theories to optimistic technical and strategic frameworks. Whereas the typical point of view emphasizes economic growth through greater resource efficiency, a refined perspective instead recognizes the limits of material cycles, both physical and systemic.

2.1.1 Circular Economy Principles and Material Loops

The most commonly cited definition comes from the Ellen MacArthur Foundation (2024), which characterizes the circular economy as a system designed to restore and regenerate resources. The classic concept of "end-of-life" is being redefined through increased engagement to fully utilize and create the most value at all times by maintaining products, components, and materials. This new definition promotes material stewardship by suggesting that superior design and a well-coordinated system can, in theory, eliminate waste. Building on this fundamental perspective, Geissdoerfer et al. (2017) outline an operational definition of the circular economy as a restorative system that minimizes resource inputs, emissions, waste, and energy loss. Firms can achieve these effects by strategically slowing, closing, and consolidating energy and material loops. From a holistic perspective, identifying specific mechanisms, such as product life extension and recycling, helps clarify how organizations operationalize "slowing" and "closing". It puts pressure on the executives to coordinate and arrange the transition away from linear practices.

Although the circular economy offers several potential benefits, its limitations and underlying assumptions warrant critical examination. Corvellec et al. (2022) argue that this concept overpromises environmental benefits and misrepresents the true costs of energy and chemicals required to maintain circularity. Skene (2018) presents physical evidence, based on the laws of thermodynamics, that the desire to close loops is physically impossible over time due to entropy and material degradation. To summarize these different angles, this report defines the circular economy as a strategic initiative to optimize material flows within inherent thermodynamic limits and the supply chain. This definition recognizes that the theoretical optimum is renewal (Ellen MacArthur Foundation). In practice, material management and selection require navigating a range of trade-offs (Skene, 2018; Corvellec et al., 2022).

The circular economy literature often describes circularity in terms of two material cycles: the biological and the technical. The Ellen MacArthur Foundation (2024) describes this structure as a Butterfly diagram, with the two continuous circular flows as the butterfly's wings. The model retains elements of a traditional linear structure, while the circular loops prevent materials from being discarded as waste. Businesses must adapt the management strategy for each resource in the loop to the item's physical properties and restoration pathway.

Non-renewable materials such as metals, polymers, and synthetic minerals are part of the technical loop, meaning they cannot biodegrade naturally. Therefore, in a circular system, these materials need to be kept in a closed loop so they can be maintained, reused, refurbished, and recycled. Preserving material quality in technical flows remains inherently difficult, as recycling can reduce material functionality and chemical integrity, particularly when recovery processes exceed thermodynamic limits (Skene, 2018). For this reason, within the technical cycle, it is important to focus on slowing the loop, meaning extending the life of the product or material.

In contrast, the biological cycle entails renewable materials such as wood-based material, natural fibers, or organic co-products. Organizations process biogenic material to enable its safe return to the biosphere. Producing products from biogenic materials often involves multiple remodeling processes; for instance, recovery actors may convert a high-value piece of furniture into a lower-grade product such as particleboard before the material fully biodegrades (Ellen MacArthur Foundation, 2024). Rosenboom et al. (2022) provide another perspective: new supply chain risks arise with the shift to bio-based materials, including variability in quality and consistency. In addition, recent research has raised concerns about hybrid biopolymer blends, such as bio-based polymers combined with non-separable synthetic components. These materials present a fundamental end-of-life challenge, as they are often incompatible with both biological and technical recovery pathways. They cannot be effectively recycled nor safely biodegraded under standard conditions (Rosenboom et al., 2022).

These disagreements create a strategic fork for decision-makers when choosing a material-selection strategy, forcing them to choose between the technical and biological cycles. Choosing the technical cycle will require investments in complex reverse logistics and in establishing new long-term partnerships with recycling firms. Meanwhile, the biological approach can ease end-of-life management, but it will instead introduce volatility in material consistency and supply chain resilience (Rosenboom et al., 2022). This study contends that the optimal material choice is not uniformly defined; rather, it depends on the business's ability to adapt and align the material's characteristics with its specific supply chain and data-tracking capabilities.

2.1.2 Value Retention and Material Limitations

A key challenge in circular flow management is creating and maintaining a high-quality loop. To address these issues, the literature uses the R-framework, which classifies strategies into three levels based on their ability to retain original value, energy, and the labor invested in materials (Kirchherr et al., 2017; Reike et al., 2018). This kind of hierarchy is fundamental to understanding the strategic trade-offs embedded in material selection, categorizing interventions from the most circular (high-order) to the least circular (low-order).

High-order strategies (refuse, rethink, reduce) emphasize refining the loop by minimizing material intensity at the early design stage. Metrics related to material efficiency are the highest priority, and by focusing on them, the firm can avoid the complexities of recovery. Medium-order strategies (reuse, repair, remanufacture) emphasize slowing the loop (Bocken & Short, 2020). These strategies are effective at retaining the functional integrity of components. Still, they impose substantial limitations on the supply chain because the materials in the flow must be durable enough to withstand multiple use cycles and disassembly. Low-order strategies (recycle, recover) are the least circular ones. Reike et al. (2018) argue that businesses can become overly reliant on recycling as their primary sustainability strategy rather than pursuing higher-order strategies that maintain material functionality. This results in downcycling, where quality is lost at each iteration, leading to thermodynamic limits on recovery (Skene, 2018).

The application of this framework indicates a significant operational trade-off. Higher-order strategies deliver greater environmental benefits and long-term resource security. However, they require a high level of transparency across the supply chain and reverse logistics, which many linear companies lack today (Farooque et al., 2019). Consequently, recycling is selected for its compatibility with the existing logistics structure rather than as the most circular solution.

The circular economy represents not only a shift in material use but also a fundamental transformation of supply chain management structures and objectives. Traditional linear supply chains prioritize efficiency in one-directional flows by moving materials from extraction through production to consumption and disposal (Mentzer et al., 2001). In contrast, circular supply chains require bi-directional material flows that incorporate recovery, reuse, remanufacturing, and recycling processes (Guide & Van Wassenhove, 2009). This structural difference introduces additional operational complexity, as firms must coordinate both forward and reverse flows while maintaining efficiency and product quality.

From a systems perspective, circular supply chains fundamentally alter the supply chain's objectives. While linear supply chains primarily prioritize cost efficiency, service levels, and delivery performance, circular supply chains introduce additional objectives, including resource recovery, lifecycle value retention, and environmental sustainability (Genovese et al., 2017; Farooque et al., 2019). This shift requires organizations to balance traditional operational performance metrics with new sustainability-related performance criteria, including material circularity, carbon footprint, and recovery efficiency. As a result, supply chain management evolves from optimizing individual transactions to managing integrated lifecycle systems.

Furthermore, implementing the circular economy transforms supply chain configurations by requiring new actors, relationships, and coordination mechanisms. Reverse logistics providers, recycling facilities, remanufacturing partners, and specialized material processors become integral components of the supply chain network (De Brito & Dekker, 2004). This transformation expands the supply chain beyond its traditional boundaries and requires firms to develop new collaborative relationships and governance structures. Consequently, the implementation of the circular economy is not simply a technical substitution of materials but a structural reconfiguration of supply chain systems.

In addition, circular supply chains require enhanced visibility and traceability across multiple lifecycle stages. Traceability systems enable firms to monitor material flows, verify recycled content, and ensure regulatory compliance (Batista et al., 2018). This increased transparency requirement reflects the transition from managing linear material flows to managing complex circular ecosystems. As a result, the implementation of the circular economy depends not only on material technologies but also on supply chain information systems and organizational coordination capabilities.

2.2 Circular Material Selection

In a circular supply chain, businesses approach material selection as more than a cost-optimized procurement task; they treat it as a strategic decision that shapes the product's overall lifecycle. Material selection shapes the path-dependent structure of the circular system, either enabling higher-order strategies or leading to lock-ins that drive a linear path of waste generation.

2.2.1 Material Criteria and Data Constraints

The needed radical shift in procurement logic is the main managerial obstacle to overcome. Viewing from the traditional way of supply chain management, where the focus is on optimizing the lead time and the unit price, treating materials as disposable inputs. To meet circularity requirements, managers must consider the total value of ownership (TVO). Xu et al. (2022) argue that the calculation should extend beyond the purchase cost to account for residual material value and the potential for secondary value after the initial lifecycle. It will cause significant economic constraints, such as the split-incentive problem. Procurement teams may favor cheaper materials to achieve short-term cost savings, rather than prioritizing circular alternatives that could reduce the long-term exposure to material price volatility.

In addition, the choice of material drives the configuration of the physical supply chain through its characteristics. The choice of material shapes determines which circular strategies are applicable, as technical and biological materials require fundamentally different recovery pathways and supply chain configurations (Bocken et al., 2016). For example, selecting high-performance, modular materials requires a supply chain design that slows the loop. Furthermore, this option requires a decentralized recovery network structure and typically moves toward a product-as-a-service model, in which the company leases products to customers. On the other hand, biological materials force a transition towards a sequential model. Stellingwerf et al. (2022) note that the primary limitation of biological materials is their flexibility, which complicates the management of biological waste when the supply chain design emphasizes precision recovery. Managers therefore face a strategic decision point at which material choices shape future partnerships, warehouse structures, and transport network investments.

New regulations create challenges for material selection, making it no longer purely a physical process but also an intensive data-management process. Zhang and Seuring (2024) highlight a transparency gap that arises from physical degradation, in which unverified or incomplete data histories can render recovered materials a significant supply chain liability. Consequently, administrative constraints may incentivize businesses to select virgin materials over recycled alternatives, as standardized certification systems often provide clearer verification of elemental composition and material origin (Yuan, 2025). This informational complexity increases due to technical risks arising from "chemical baggage". Vilaplana and Karlsson (2008) note that a material loses its functionality and chemical integrity when it circulates through various industrial loops due to the accumulation of contaminants, residual additives, and polymers. Therefore, managers must weigh the trade-offs between achieving environmental sustainability goals and the legal and operational safety requirements shaped by the virgin material's data history. A lack of clear visibility into the material's previous lifecycles creates risks related to product safety and regulatory compliance, and a typical linear supply chain design is not structurally suitable to mitigate these risks (Vilaplana & Karlsson, 2008; Zhang & Seuring, 2024).

2.2.2 Strategic Sourcing and Organizational Capabilities

Strategic sourcing theory emphasizes that procurement decisions play a critical role in shaping supply chain performance and competitive advantage, recognizing procurement as a strategic function that influences supplier relationships, product quality, innovation potential, and long-term supply chain resilience (Chen et al., 2004). In circular supply chains, procurement decisions become even more strategically significant because material selection determines the feasibility of reuse, remanufacturing, and recycling.

Supplier selection represents a core element of strategic sourcing. Traditional supplier selection criteria focus primarily on cost, quality, and delivery reliability (Weber et al., 1991). However, circular supply chains introduce additional selection criteria, including material traceability, recyclability, environmental performance, and supplier recovery capabilities (Govindan et al., 2015). These circularity-related supplier criteria increase the complexity of procurement decision-making, as firms must evaluate suppliers based on their ability to support circular material flows rather than solely on their capacity to deliver virgin materials efficiently.

Furthermore, strategic sourcing involves developing long-term relationships between firms and suppliers to ensure supply stability and improve performance (Chen et al., 2004). Circular supply chains intensify the importance of such relationships, as material recovery, reuse, and recycling processes require close coordination between supply chain partners. Firms must collaborate with suppliers to develop circular-material capabilities, ensure consistent material quality, and establish reverse-logistics systems. These collaborative requirements highlight the strategic role of procurement in enabling the circular economy. Additionally, procurement decisions influence supply chain risk exposure and resilience. Circular materials often involve supply uncertainty due to limited availability, variable quality, and immature recycling infrastructures (Guide & Van Wassenhove, 2009). Strategic sourcing enables firms to mitigate these risks by diversifying suppliers, developing long-term partnerships, and investing in supplier capabilities. Therefore, procurement becomes a critical enabler of circular supply chain transformation.

The resource-based view (RBV) offers a useful theoretical perspective for understanding the implementation of circular supply chains. According to the RBV, firms achieve competitive advantage by developing valuable, rare, inimitable, and non-substitutable organizational resources and capabilities (Barney, 1991). Implementing a circular economy requires firms to develop new capabilities, including reverse logistics management, material traceability systems, and supplier integration.

Organizational capabilities play a critical role in enabling the adoption of circular materials. Firms must develop technical expertise to evaluate material performance, establish traceability systems to verify material origins, and coordinate recovery and recycling processes among supply chain partners (Teece et al., 1997). These capabilities represent dynamic organizational competencies that enable firms to adapt to changing environmental and regulatory requirements. Furthermore, capability constraints are a major barrier to implementing the circular economy. Firms lacking reverse logistics infrastructure, traceability systems, or supplier integration capabilities face structural limitations in adopting circular materials (Ketokivi & Choi, 2014). These limitations help explain why circular economy adoption varies across firms and industries, as developing organizational capabilities requires time, investment, and learning.

The RBV also highlights the importance of supply chain integration capabilities. Effective coordination between supply chain partners enables material recovery, quality assurance, and traceability verification (Flynn et al., 2010). Firms can implement circular-material strategies more effectively by developing strong integration capabilities. The role of the integration capabilities demonstrates that circular economy implementation depends not only on material availability but also on the organizational and supply chain capabilities required to coordinate circular material flows.

2.3 Decision-Making and Trade-offs in Material Choices

2.3.1 Decision-Making Under Constraints

Traditional operations and supply chain models often assume that organizational decisions can be optimized once sufficient information and analytical capability are available. However, behavioral operations research demonstrates that real decision environments rarely meet these assumptions. Decision-makers operate under limited information, time pressure, and competing performance objectives, and therefore rely on simplified decision rules rather than full optimization (Bendoly et al., 2006). When multiple performance dimensions must be considered simultaneously, such as environmental performance, cost efficiency, operational feasibility, and customer requirements, managers tend to seek acceptable solutions rather than optimal ones (Croson et al., 2013). Consequently, material selection in circular supply chains becomes a prioritization problem in which certain criteria function as constraints while others remain adjustable (Pagell & Shevchenko, 2014).

This perspective is particularly relevant in circular supply chains because decisions involve multiple performance dimensions simultaneously. Material selection requires evaluating environmental performance, cost efficiency, operational feasibility, regulatory compliance, and customer expectations simultaneously. Decision-makers cannot simultaneously maximize these objectives, and this constraint fundamentally alters the nature of the decision problem. Instead of pursuing full optimization, decision-makers must determine which criteria define acceptable limits and which criteria allow adjustment (Pagell & Shevchenko, 2014).

In practice, organizations treat some requirements as non-negotiable constraints. Safety, technical functionality, and regulatory compliance typically serve as hard constraints, as failure to meet them prevents the product from entering the market. Other criteria, such as cost levels or environmental improvements, are negotiable within acceptable ranges. Wu and Pagell (2011) show that firms typically consider sustainability only after ensuring operational feasibility. Consequently, circular alternatives are not compared directly with linear ones; they pass through a feasibility filter before firms assess their economic or environmental performance. This constraint-handling logic implies that circular solutions fail not primarily because they lack environmental value, but because they fail to meet operational thresholds. The decision problem, therefore, becomes one of compatibility rather than superiority.

Supply chain decisions rarely occur within a single decision-maker. Instead, they emerge from interaction between organizational functions with different performance objectives. Procurement departments typically prioritize cost efficiency and supply reliability; engineering departments prioritize functionality and safety; marketing emphasizes customer acceptance; and sustainability functions promote environmental performance. These different evaluation logics create internal goal conflicts. Wu and Pagell (2011) demonstrate that sustainability initiatives often stall not because of a lack of environmental benefits but because they conflict with other functional priorities. Organizations, therefore, do not maximize sustainability outcomes; they attempt to maintain acceptable performance across multiple dimensions simultaneously. Pagell and Shevchenko (2014) describe this as a paradoxical decision environment in which organizations cannot resolve trade-offs analytically but must manage them organizationally.

Within such environments, decision-making tends to follow an implicit hierarchy of priorities. Functional feasibility typically comes first because it determines whether a product can exist at all. Economic feasibility follows, as firms must remain competitive and financially viable. Environmental performance is considered only after these requirements have been satisfied. Sustainability, therefore, becomes conditional: improvements occur when they align with operational and economic requirements, rather than independently of them. This prioritization does not necessarily imply that firms disregard sustainability. Instead, it reflects the need to integrate sustainability into existing operational systems rather than replace them.

Material selection decisions have long-term consequences because they shape the supply chain's structure. Once a material is adopted, it determines supplier relationships, processing technologies, logistics networks, and recovery possibilities. These structural commitments create path dependency, meaning that current decisions constrain future options. Ketokivi and Choi (2014) argue that operational decisions are embedded in organizational routines and capabilities, leading firms to favor solutions compatible with existing systems. Circular materials that require new infrastructure, coordination mechanisms, or competencies may therefore be rejected despite their superior environmental performance. Montabon et al. (2016) similarly emphasize that the implementation of the circular economy depends on organizational feasibility rather than theoretical desirability. Firms, therefore, evaluate materials not only based on their technical properties but on the organizational changes they imply. Because such changes involve risk and investment, organizations tend to prefer incremental adaptations rather than radical transformation (Bocken et al., 2016).

Consequently, circular material selection functions as a governance process rather than a purely technical comparison.

2.3.2 Cost, Customer, and Performance Trade-offs

Sustainable supply chain management (SSCM) is typically seen as the integration of environmental, social, and economic objectives into the supply chain, rather than treating sustainability as a separate activity. Carter and Rogers (2008) define SSCM as the strategic and transparent integration of these sustainability dimensions to improve long-term economic performance and competitive advantage, highlighting that sustainability expands the objective function of supply chain management beyond traditional cost and service priorities. Building on this, Seuring and Müller (2008) show in their literature review that sustainability requirements are often driven by stakeholder and regulatory pressures and translated into supply chain practices such as supplier management and product-related initiatives. Together, these perspectives imply that decision-makers in SSCM rarely evaluate material and sourcing decisions based on a single criterion; instead, they assess them across multiple concurrent performance dimensions, thereby creating tensions between objectives as a common decision condition (Carter & Rogers, 2008; Seuring & Müller, 2008).

A recurring theme in SSCM research is that sustainability initiatives can introduce additional costs or resource commitments that may conflict with short-term cost-efficiency targets. Seuring and Müller (2008) identify cost-related barriers in implementing sustainable supply chain practices, including the need for supplier development, monitoring, and coordination, which can require investments and increase operational effort. Hassini et al. (2012) present a similar view, arguing that sustainable supply chain initiatives often require additional resources. They further emphasize that the challenge lies not only in implementing such practices, but also in evaluating performance and making the business case, particularly when sustainability metrics are less standardized than financial measures. This aligns with Seuring and Müller's (2008) view that decision-makers often face economic tension when sustainability improvements require investments or generate cost increases that organizations need to justify internally or incorporate into pricing strategies.

Beyond cost, SSCM decisions must be compatible with customer requirements and operational performance, creating additional trade-offs. Pagell and Wu (2009) argue that firms must embed sustainability within operational processes while maintaining competitiveness and meeting customer expectations. Sustainability does not replace core business requirements; rather, businesses must incorporate it into their core operations. Wu and Pagell (2011) further argue that organizations implementing sustainability measures make decisions under multiple constraints and balance environmental goals with operational requirements such as product performance, quality, and delivery expectations. Their findings suggest that organizations make sustainability-related decisions by prioritizing among competing objectives and managing constraints. In practice, decision-makers assess environmental goals alongside customer requirements and operational feasibility, which may limit the extent to which businesses can pursue environmental objectives (Pagell & Wu, 2009; Wu & Pagell, 2011).

2.3.3 Risk, Uncertainty, and Cross-Functional Prioritization

SSCM and related circular supply chain initiatives may also introduce uncertainties that affect sourcing and planning. While SSCM research acknowledges that sustainability can reshape supplier relationships and introduce capability constraints (Seuring & Müller, 2008), closed-loop supply chain research specifically highlights the uncertainty surrounding reverse flows and recovery systems. Guide and Van Wassenhove (2009) note that closed-loop supply chains face uncertainty in the timing, quantity, and quality of returns, which increases complexity and complicates planning and coordination compared to traditional supply chains without return flows. This uncertainty may affect supply reliability and operational stability. Decision-makers must therefore weigh sustainability and circularity goals against risk exposure and feasibility constraints when making supply chain decisions (Guide & Van Wassenhove, 2009; Seuring & Müller, 2008).

Rather than presenting sustainability as a purely technical optimization problem, literature describes SSCM as a managerial challenge involving integration, prioritization, and decision-making across multiple functions and across the supply base. Carter and Rogers (2008) argue that SSCM is strategic in nature and must be integrated into broader management systems to generate long-term value. Wu and Pagell (2011) suggest that organizations balance sustainability with other priorities through decision processes that recognize multiple constraints and attempt to maintain acceptable performance across dimensions. Trade-offs are not out of the ordinary but are part of the normal decision-making environment in SSCM, requiring firms to develop structures and processes to evaluate sustainability alongside cost, customer requirements, and operational feasibility (Carter & Rogers, 2008; Wu & Pagell, 2011).

Trade-offs in sustainable supply chains emerge from the need to balance multiple performance objectives simultaneously. Traditional supply chain management emphasizes cost efficiency, service levels, and operational performance, while sustainability introduces additional environmental and social objectives (Pagell & Shevchenko, 2014). These objectives often conflict, as improving environmental performance may require increased costs, process changes, or new supplier relationships. Temporal trade-offs also play a significant role in implementing the circular economy. Circular materials often entail higher short-term costs due to infrastructure investments, certification requirements, and limited supply (Bocken et al., 2016). However, circular strategies may yield long-term benefits by improving resource efficiency, reducing material costs, and ensuring regulatory compliance. Yet they can create a temporal misalignment between investment costs and realized benefits, which may discourage circular adoption. Organizational trade-offs also emerge from differences in functional priorities within firms. Procurement departments often prioritize cost efficiency, engineering departments prioritize technical performance, and sustainability departments prioritize environmental objectives (Wu & Pagell, 2011). These differing priorities create internal tensions that influence material selection decisions. Additionally, trade-offs arise from the uncertainty surrounding circular materials. Variability in material quality, availability, and recovery rates increases supply chain risk (Guide & Van Wassenhove, 2009), reinforcing the complex decision environment associated with circular material selection.

2.4 Circular Supply Chain Design

2.4.1 Closed-Loop Structures and Reverse Flows

While conventional linear supply chains typically manage only the forward flow of products from the raw material supplier through production and distribution to disposal, circular supply chains must also manage reverse flows back to the original producer for reuse, remanufacturing, or recycling. To achieve this, circular supply chains retain value within the material itself and avoid excess resource consumption and waste by incorporating a reverse-flow component. Guide and Van Wassenhove (2009) define closed-loop supply chains as systems that integrate forward and reverse logistics to enable the recovery and reintroduction of materials into production cycles. This integration requires organizations to manage material flows across multiple lifecycle stages rather than focusing solely on forward production and distribution.

When reverse logistics is added to an organization's supply chain, it introduces significant additional structural and operational complexity beyond that of a typical supply chain. De Brito and Dekker (2004) explain that reverse logistics involves planning, implementing, and controlling the flow of used products and materials to recover value or ensure proper disposal. These processes include collection, inspection, sorting, and recovery, which businesses need to coordinate with their existing production and logistics operations. As a result, organizations implementing circular material flows must develop additional capabilities to manage these processes effectively.

2.4.2 Network Design, Sourcing, and Planning

The implications of integrating circular material flows into supply chain network design and sourcing strategies are significant. Circular supply chains typically require additional infrastructure, such as collection points, sorting centers, and recovery operations, which must be integrated into the existing supply chain network. Fleischmann et al. (1997) demonstrated that reverse logistics add new types of facilities and new types of material flows to the overall design of the supply chain network, which increases the complexity of the design and requires organizations to consider both forward and reverse material flows when determining the location of facilities and designing transportation networks.

The impact of circular materials on both network structure and sourcing strategy also extends to organizations' relationships with their suppliers. A circular supply chain often requires an organization to develop a sourcing strategy that relies on obtaining materials from either recycling operations or specialized suppliers, which may not be located near one another. In addition, organizations must coordinate the activities of multiple stakeholders when recovering and processing materials into a reusable form. Genovese et al. (2017) provide evidence that organizations need to develop new supply chain configurations and partnerships to effectively manage the inherent complexity of achieving circularity. Organizations will also need to enhance their collaboration with suppliers and other partners involved in material recovery and processing to ensure the quality, availability, and compliance of materials with acceptable technical specifications.

Circular material flows also introduce uncertainty and variability, affecting supply chain planning and operational processes. Unlike virgin materials, which typically have predictable supply characteristics, circular materials exhibit greater variability in availability, timing, and quality depending on recovery processes and the effectiveness of return flows. Guide and Van Wassenhove (2009) write that uncertainty in material return flows represents a key challenge in closed-loop supply chains, affecting sourcing decisions, inventory management, and production planning. Due to this new level of uncertainty, organizations must allow for new modes of planning and coordination to manage materials that flow in circular flows effectively.

Supply chain network design involves determining the optimal configuration of suppliers, production facilities, warehouses, and distribution channels to achieve organizational objectives (Simchi-Levi et al., 2008). Network design decisions influence transportation costs, lead times, inventory levels, and supply chain responsiveness. Circular supply chains introduce additional complexity in network design by incorporating reverse logistics flows. Recovery facilities, recycling centers, and remanufacturing operations must be integrated into existing supply chain networks (Fleischmann et al., 1997). Geographic considerations also play a critical role in circular network design. Recycled materials are often sourced locally due to transportation costs and environmental considerations (Genovese et al., 2017). This reliance on local sourcing may encourage regionalization of supply chains, reducing dependence on global sourcing networks. Firms must strategically locate recovery facilities, coordinate supplier relationships, and ensure material availability, demonstrating that adopting circular materials requires structural changes to supply chain networks.

2.4.3 Complexity, Coordination, and Traceability

Supply chain complexity increases significantly in circular systems due to the integration of reverse flows and recovery processes (Choi et al., 2001). Circular supply chains must manage multiple material flows, recovery processes, and supplier relationships simultaneously. Circular materials also introduce supply uncertainty due to variability in return rates, material quality, and availability (Guide & Van Wassenhove, 2009). This uncertainty complicates supply chain planning and inventory management. Additionally, circular supply chains require enhanced coordination between supply chain actors. Firms must collaborate with suppliers, recyclers, and logistics providers to ensure the availability and quality of materials (Genovese et al., 2017). This increased complexity requires firms to develop advanced planning and coordination capabilities to manage circular material flows effectively.

2.5 Conceptual Framework

Based on the theoretical perspectives presented in the preceding sections, we can develop a conceptual framework to illustrate the relationships among external drivers, organizational decision-making processes, trade-offs, and the impacts of supply chain design on circular material selection.

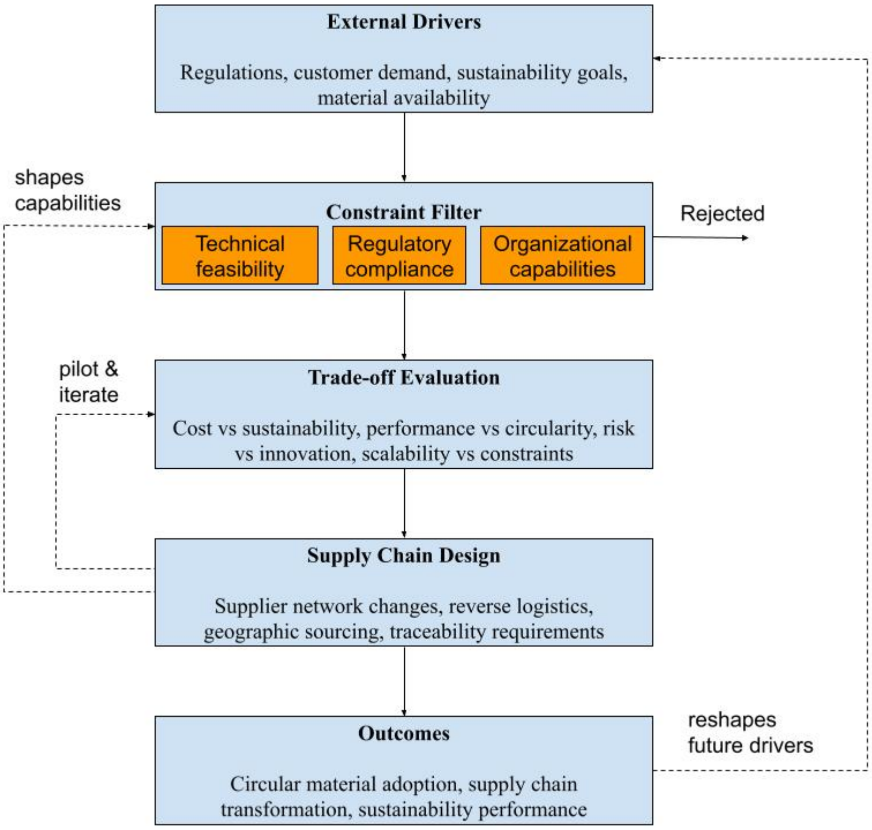

Figure 1. Conceptual framework of circular material selection and supply chain impacts.

The conceptual framework presented in Figure 1 illustrates how circular material selection decisions emerge and how they influence supply chain design and sustainability outcomes. The framework integrates theoretical perspectives from circular economy, sustainable supply chain management, material selection, and supply chain design to provide a structured understanding of the sequential relationships among external drivers, constraints, trade-offs, and supply chain transformation.

At the top of the framework, external drivers represent the contextual factors that initiate circular material selection decisions. These include regulatory requirements, customer sustainability expectations, corporate sustainability goals, and material availability constraints. As highlighted in the theoretical review, regulatory pressures and stakeholder expectations influence organizations by shaping supply chain practices and sourcing decisions (Carter & Rogers, 2008; Seuring & Müller, 2008). These drivers create both incentives and constraints for the adoption of circular materials and influence organizational priorities and decision-making processes.

Below this, the constraint filter serves as the mechanism for screening material alternatives before any trade-off evaluation. Rather than entering a balanced multi-criteria decision process, materials must first clear three sequential gates: technical feasibility, regulatory compliance, and organizational capability. Materials that fail any gate are rejected from the process entirely and never reach sustainability evaluation. The rejection of materials that fail any gate shows that feasibility-based logic governs circular material selection. This logic takes priority over environmental optimization alone and aligns with bounded rationality theory and the organizational goal conflict perspective described by Wu and Pagell (2011) and Pagell and Shevchenko (2014). Unlike technical feasibility and regulatory compliance, which function as hard constraints, organizational capability is expandable over time through investment in infrastructure, supplier development, and traceability systems. This distinction is important because the constraint filter is not static, but it evolves as organizations build circular competencies. The feedback mechanism described below captures this evolution.

The framework further identifies trade-offs as a central mediating element between the constraint filter and supply chain outcomes. Only materials that pass all three gates reach this stage, where the evaluation considers competing objectives related to cost, performance, supply chain risk, and sustainability. Importantly, sustainability is included in the evaluation conditionally, only after the material satisfies operational and regulatory thresholds. Organizations must balance environmental objectives with economic feasibility and operational stability, resulting in trade-offs that influence decision outcomes and implementation feasibility.

These trade-off evaluations subsequently influence supply chain design, as illustrated in the next stage of the framework. Material selection decisions affect supplier relationships, sourcing strategies, logistics systems, and traceability requirements. Adopting circular materials may require organizations to establish new supplier partnerships, integrate reverse logistics processes, and implement enhanced traceability systems (Guide & Van Wassenhove, 2009). These requirements demonstrate that material selection functions as a key driver of supply chain configuration and structural transformation.

At the bottom of the framework, these structural changes lead to supply chain and sustainability outcomes, including the adoption of circular materials, supply chain transformation, and improvements in sustainability performance. These outcomes feed back into the system through two mechanisms. First, outcomes reshape future external drivers, as regulatory landscapes, customer expectations, and material availability evolve in response to circular adoption. Second, supply chain design decisions shape future organizational capabilities. Investments in reverse logistics, traceability, and supplier development increase the volume passing through the constraint filter in subsequent cycles. These investments also reduce barriers that previously prevented the process from accepting certain materials. A pilot-and-iteration loop between trade-off evaluation and supply chain design further underscores that companies test and adjust incrementally before committing to broader structural change.

Overall, the conceptual framework provides a structured explanation of the circular material evaluation process. It shows how external drivers initiate evaluation, how feasibility constraints filter available options, and how trade-offs mediate implementation decisions. It also explains how adopting circular materials subsequently transforms supply chain structures. The feedback mechanisms capture the dynamic and iterative nature of circular supply chain development, recognizing that material selection is not a one-time decision but an evolving organizational process.

3. Methodology

This chapter describes the research methodology used to address the research questions. It outlines the research design, data collection, and data analysis methods, and explains how the empirical data were gathered and analyzed. The chapter also discusses the rationale for the chosen methodological approach, as well as considerations regarding research quality and ethical issues.

3.1 Research Design

This study adopts a qualitative research approach to explore how organizations manage circular material choices and integrate circularity into supply chain decision-making processes. Qualitative research is appropriate when the objective is to understand complex organizational phenomena, interpret decision-making behavior, and examine how actors reason within real operational contexts (Bell et al., 2019; Petty et al., 2012).

Circular material selection involves technical feasibility, economic constraints, regulatory compliance, and organizational coordination, making it unsuitable for purely quantitative measurement approaches. Instead, understanding how decisions are prioritized and justified requires access to participants' interpretations and experiences.

The research follows an exploratory design, as circular material decision-making remains an emerging practice with limited empirical investigation in operational supply chain settings. Exploratory research is particularly suitable when existing theory does not sufficiently explain how a phenomenon occurs in practice and when the purpose is to develop conceptual understanding rather than test causal hypotheses (Bell et al., 2019).

Rather than studying a single organization, the research investigates multiple companies across different industries. This multi-organizational perspective enables the identification of recurring decision patterns independent of specific organizational structures. And instead of aiming for statistical generalization, the objective is to identify recurring mechanisms and decision logics across organizational contexts and thereby develop analytical and conceptual understanding of how circular material decisions are made in practice.

The study follows an abductive research approach, iteratively combining theoretical concepts and empirical observations. Initial literature informed the interview structure and sensitizing concepts, while empirical findings continuously refined the analytical categories. This iterative process allowed theory and data to inform each other throughout the research, which is appropriate when investigating complex organizational decision processes (Dubois & Gadde, 2002).

3.2 Research Context and Participant Selection

Participants were selected using purposive sampling, meaning individuals were chosen based on their relevance to the research phenomenon rather than representativeness (Bell et al., 2019). The objective was to interview professionals directly involved in material selection, sustainability evaluation, product development, procurement, or supply chain decision-making related to circular materials.

The study includes participants from organizations operating across several industrial sectors, including manufacturing, industrial production, heavy vehicles, logistics, MedTech, defense, retail, and energy. This diversity was intentionally sought to observe whether decision logic is context-specific or structurally similar across industries.

The interviewees held roles such as procurement specialists, sustainability experts, engineers, supply chain professionals, and managerial decision-makers. These roles were selected because they directly participate in evaluating material alternatives and balancing technical performance, cost, and sustainability requirements.

In total, 11 companies participated. Companies were identified through professional networks and targeted outreach based on their engagement in sustainability initiatives or material-related decision processes. The aim was to achieve variation in decision environments rather than statistically represent industries.

The sampling logic, therefore, emphasized decision relevance and information richness. Interviewing individuals actively engaged in material selection increases the likelihood that responses reflect actual organizational practices rather than general sustainability opinions. The inclusion of 11 companies was considered sufficient for analytical generalization, as recurring patterns and themes began to emerge across the interviews.

3.3 Data Collection

This section presents the data collection process applied in the study. First, the use of semi-structured interviews as the primary empirical method is described, followed by an explanation of how the interview guide was developed to ensure alignment with the research questions and theoretical framework.

3.3.1 Semi-Structured Interviews

Semi-structured interviews were used as the primary data collection method. This format allows a consistent thematic structure while enabling participants to explain reasoning and provide context-specific examples (DeJonckheere & Vaughn, 2019).

The method is particularly suitable for studying decision-making processes because it clarifies motivations, constraints, and trade-offs during the conversation. In addition, semi-structured interviews provide sufficient flexibility to follow up on emerging themes while still maintaining comparability across interviews (Kallio et al., 2016).

Each interview lasted approximately 30–60 minutes and was conducted via video conference. Interviews followed a consistent structure: an introduction to the study, a thematic discussion aligned with the research questions, and clarifying questions.

With participant consent, all interviews were recorded to ensure accurate documentation (Bryman & Bell, 2019). Follow-up questions were frequently used to confirm interpretations during the interview and to elicit elaboration on specific examples from practice. This reduced the risk of misinterpretation by researchers and strengthened the credibility of the collected material. Except for one interview conducted in English, all interviews were carried out in Swedish. Quotes presented in the empirical findings have been translated into English by the authors. Care was taken to preserve the original meaning, though minor linguistic adaptations were necessary during translation.

After each interview, reflective notes were written to document preliminary observations and emerging patterns.

Table 1: Overview of interviewed Companies

Company	Industry	Respondent's role	Duration (minutes)
A	Logistics & distribution	Supply chain & logistics manager	44
B	Power systems manufacturing	Operations & HSE Manager	43

C	Industrial equipment	Procurement & R&D specialists	66
D	Fashion retail	Material strategy & sustainability managers	46
E	Home decor retail	Material strategy & sustainability managers	32
F	Industrial technology	Senior sustainability manager	38
G	MedTech	R&D & sustainable procurement managers	49
H	Defense	Compliance & material specification manager	47
I	Heavy vehicles	Production & tooling engineer	41
J	Steel production	Supply chain & sales manager	56
K	Automotive production	Procurement specialist	48

3.3.2 Interview Guide Development

The interview guide was developed based on the research questions and the theoretical framework for the circular economy and circular material selection. The guide included questions designed to explore:

- How do companies evaluate circular material alternatives?
- What criteria influence material selection decisions?
- What challenges do companies face when implementing circular materials?
- How does circularity affect supply chain design and organizational processes?

The guide was designed to be flexible, allowing follow-up questions to explore specific topics in greater depth. This flexibility is a key advantage of semi-structured interviews, as it allows researchers to adapt questions to participants' responses while maintaining consistency across interviews (Kallio et al., 2016).

3.4 Data Analysis

The collected interview material was analyzed using thematic analysis to identify recurring patterns and key themes related to circular material selection and supply chain decision-making. Thematic analysis is a qualitative analytical method that enables systematic examination of textual data by organizing it into meaningful categories and themes (Braun & Clarke, 2006).

The analysis began with transcribing all interview recordings to create a complete textual dataset. This step ensured that the empirical material could be examined in detail and supported a structured analysis process.

After transcription, the interview transcripts were read multiple times to develop a comprehensive understanding of the content and to identify initial observations relevant to the research questions. This familiarization phase was important for identifying recurring issues and early patterns across the interviews.

Following familiarization with the data, meaningful segments of text were identified and labeled using initial codes. These codes represented important concepts related to how companies evaluate circular material alternatives, the criteria influencing material selection, and the organizational implications of adopting circular materials.

The coded data were subsequently reviewed and grouped into broader categories based on conceptual relationships. For example, codes related to safety requirements, technical functionality, and regulatory compliance were grouped into broader categories concerning feasibility constraints.

These categories were then refined into overarching themes that capture key aspects of circular material decision-making, including evaluation criteria, operational constraints, trade-offs, and supply chain implications.

Throughout the analysis, an iterative and abductive approach was applied, involving repeated movement between the empirical data, the identified codes, the emerging themes, and the theoretical framework. This process allowed refinement of the analytical structure and ensured that the findings accurately reflected the perspectives and experiences of the interview participants (Petty et al., 2012).

The resulting themes served as the basis for presenting and analyzing the empirical findings in subsequent chapters.

3.5 Research Quality and Ethics

Ensuring research quality is essential in qualitative research to ensure that findings are credible and trustworthy. This study adheres to the qualitative research quality criteria outlined by Korstjens and Moser (2018), namely credibility, dependability, confirmability, and transferability.

Credibility refers to the extent to which the findings accurately represent participants' perspectives. This was supported by conducting interviews with participants directly involved in material selection and circularity decision-making, using follow-up questions during interviews, and repeatedly revisiting the transcripts during analysis.

Dependability refers to the consistency and transparency of the research process. This was ensured by documenting the research design, interview procedures, coding process, and theme development, creating a transparent methodological trail.

Confirmability refers to the extent to which the findings are based on participant data rather than researcher bias. This was supported by systematically analyzing interview transcripts, grounding findings in empirical evidence, and continuously discussing interpretations among the researchers (Korstjens & Moser, 2018).

Transferability was supported by providing detailed descriptions of the participating sectors, organizational roles, and decision contexts, enabling readers to assess the relevance of the findings in other settings.

Reflexivity was also considered throughout the research process. Since qualitative research is inherently interpretative, the researchers continuously reflected on how their prior knowledge in supply chain management and sustainability might influence data interpretation and theme development.

Ethical considerations were addressed throughout the research process. Participants were informed of the study's purpose, and their participation was voluntary. Participant identities and company information were treated confidentially to ensure anonymity.

3.6 Digital Tools and AI

Digital tools were used to support the research process, particularly for data transcription, language refinement, and text organization.

Interview recordings were initially transcribed using Chalmers AI Portal to convert audio data into text. The use of digital transcription tools can improve efficiency in qualitative research by reducing the time required for manual transcription and supporting the management of large textual datasets (Castleberry & Nolen, 2018).

Following transcription, all transcripts were manually reviewed and corrected to ensure contextual accuracy and proper interpretation of participant responses. Manual review was considered necessary to reduce the risk of transcription errors and to ensure that terminology, industry-specific expressions, and contextual meanings were accurately represented in the empirical material.

Artificial intelligence tools such as ChatGPT, Gemini, and Grammarly were used only to support language refinement, proofreading, and structural text editing. These tools were not used to generate empirical findings, conduct coding, develop themes, or replace analytical interpretation.

All empirical analysis, coding, theme development, and theoretical interpretation were conducted exclusively by the researchers to ensure that the findings accurately reflect the collected empirical data and remain grounded in the interview material. The use of digital tools and AI followed established principles of research transparency and academic integrity. AI tools served solely as supportive tools to improve readability and linguistic clarity, without influencing the interpretation of the empirical results (Stahl & Eke, 2024).

4. Empirical Findings

This chapter presents the empirical findings from the conducted interviews. The findings describe how circular material selection decisions are made, what trade-offs emerge, and how these decisions influence supply chain design. The chapter is structured according to the research questions and presents the empirical data without interpretation, providing the foundation for the analysis in Chapter 5.

4.1 Decision-Making in Circular Material Choices

A transition from linear to circular material-flow systems involves not only technological substitution but also a total organizational shift in how value is validated and perceived. Section 4.1 presents empirical findings on the decision-making process for eleven case companies, anonymized as Companies A-K. The data is structured as follows: initiation stage, evaluation criteria, value quantification, stakeholder dynamics, and operational implementation barriers.

4.1.1 Strategic Initiation and Procedural Flows

The empirical findings from the interviews indicate a clear distinction in how transitions involving circular materials are initiated. Two primary pathways are identified: Strategic top-down mandates and autonomous operational scouting.

Strategic top-down mandates are seen in heavy industrial and high-complexity sectors, where initiation is almost exclusively top-down; for instance, steel (Company J) and Heavy vehicles (Companies K and I). Respondent from Company J describes the transition to fossil-free steel as a central directive: “It is very top-down steered…. Directives from group management take this into our assortment and then build a market for it”. Meaning that the board acts as the primary initiator in industries where the material production is its core product. Likewise, Company K has regularized this by creating and appointing a specialized group, a “Fossil-free material group”. As the respondent from Company K described, “We have a target set by the fossil-free material experts that we should have, for example, 30% recycled plastic in plastic components and 50% recycled aluminum in aluminum components.” This team sets the standard and high-level targets, which the procurement unit is then obligated to operationalize in future contracts.

Autonomous operational scouting is evident in retail and fashion (Companies D and E), where initiatives take a decentralized approach. Respondent from Company E mentions that the material sourcing teams operate with substantial autonomy: “Teams are quite autonomous in how they work to secure material goals… Material teams source the material themselves.” Initiation, in this context, starts with trade fairs or direct supplier proposals. Company A (logistics) notes that the initiative is even more localized: it takes the form of unique pilot projects designed to address specific customer needs; for instance, the X project, in which seasonal workwear is returned, refurbished, house-kept, and redistributed.

The regulatory-driven initiation is also evident in empirical findings from companies in which external forces serve as the trigger, meaning they are strictly regulated, with laws and policies setting the rules for initiation. It can be seen in companies in the military industry (Company H) and MedTech (Company G). These two companies rely on hazardous substance lists (REACH/RoHS) as their key starting point. Company H noted: “Regulations steer most material things... The EU bans them, so you must come up with alternative materials.” Consequently, the decision-making process is different: it is not a choice-based “if”; instead, it is a technical race of “how”. Despite industry differences, a general five-stage material selection process was identified across all the case companies.

1. Identification and scouting, where sourcing teams identify various circular alternatives such as recycled, biobased, or local materials. For Company C (Industrial), the first step is highly flexible and involves early dialogue with the R&D department and suppliers.
2. Technical Validation is the step in which the chosen material undergoes testing. Company G points out that new suppliers must undergo a proper “qualification” process, in which a check for science-based targets and ethical compliance is conducted before laboratory testing begins.
3. Cross-functional benchmarking, meaning comparing different presented options. For instance, at Company I, the procurement department is presenting three alternatives to management: safety, environmental impact, and cost.
4. From Company B's perspective, the formal declaration and governance step is as follows: every change is documented in the “HLM” for each project. When the changes have a greater impact, the decision is escalated to the board or to a steering group under the board.
5. A pilot and scaling program, where an implementation plan is settled, starting within a region or with a specific product that is later evaluated before scaling and incorporated into the global supply chain.

4.1.2 Evaluation Criteria and Quantification of Circular Value

An important finding is the presence of a hierarchical gatekeeper model, in which the only way to achieve sustainability is first to satisfy the technical and safety criteria.

- Technical performance and safety
    - For companies in the medical and transport sectors, the performance metrics are a non-negotiable blocker. Respondent from Company I states, “Priority 1 would be strength calculations and safety. If it involves the safety of the operator or people driving the truck, it is the highest priority.*”* Similarly, Company G made this explicit: “Function above all. Does it fulfill the requirement of healing a wound? We simply cannot compromise on our mission. We are here to heal wounds. That is what we do.” Material choices that might compromise sterility or biocompatibility would not be considered regardless of their environmental benefits. Company K emphasizes that some metals, like aluminum, can tolerate impurities. Still, copper is less tolerant of even minor changes in alloy composition, which can lead to catastrophic heat failure.

- Traceability and Purity
    - Company F (Energy) and Company E (Home decor) have traceability as the primary sustainability criterion. Company E requires a comprehensive supply chain overview to verify the origin of the recycled fibers. Company F identifies traceability as the mechanism for ensuring that “legacy toxins” are not reintroduced into the system through recycling activities. Company C (Industrial) has high premiums for “Purity” on technical components such as seals, where reformed materials cannot meet the standard and are disqualified due to the risk of mechanical failure.

- Material availability and scalability
    - A continuous operational problem is the availability of materials and whether they are available in sufficient quantities. Company D (Fashion) and Company I (Heavy Vehicles) observed that, while a circular alternative might be technically ideal, global production capacity is insufficient to meet the companies' mass-production needs.

The empirical findings reveal a marked valuation disparity between firms that use advanced LCA tools and those that rely on qualitative assessments. Companies J and K use environmental product declarations (EPDs) as certificates and to communicate value. These EPDs are used in sales meetings to demonstrate the environmental quality of the steel they have produced or used in their products. Company F employs the Circular Transition Indicators (CTIs) framework to calculate all circular inputs and outputs, which later provides a "circularity score". Company C has developed an internal calculation matrix, a tool that allows the purchaser to input the chosen energy source (e.g., fossil fuel vs. green electricity) and transport distances to quantify CO2 emissions, integrating sustainability into price comparisons.

Although two companies, A and B, affirmed that the whole quantification process can be struggling. Company A encountered difficulties in valuing and comparing circular solutions, leading to a case-by-case approach without standardized benchmarking. Company B is using a general LCA data tool, but admits it remains a generalization, making it difficult to apply to specific component decisions.

4.1.3 Governance and Implementation Challenges

The material selection process works cross-functionally, meaning that different departments of a company can have a "veto" or advisory powers to make the final call. In Companies B, C, H, and I, the R&D and design departments function as gatekeepers, defining the product's technical specifications. The sustainability department serves as a sustainability advisor but, but in most cases, it lacks executive authority. The sustainability team in Company F can "indicate" a preference, but the portfolio managers and supply chain teams take the final decision. Company G has created a unique group focused on sustainable procurement and serving as a bridge to help category managers meet climate and sustainability targets without compromising quality or cost. The executive managers are seen as the visionaries, planning future strategies, for instance, Company J's transition to fossil-free steel or Company A's transition to offering service-based models. The board made these decisions because they fundamentally alter the company's financial risk profile.

The implementation stage is where industrial reality meets theoretical circularity. Company K provided the most technical challenge regarding the recycled copper: *"If we change from pure copper to copper alloy(recycled)... we would have typically 40% more heat in the box… it would go over the melting point for the industrial plastic on the connectors."* It illustrates that the laws of physics limit the circular potential of high-performance products. As with recycled fibers mentioned by Company D, shorter recycled fiber lengths lead to lower fabric stability and increased pilling, creating a “Quality vs. Sustainability” trade-off.

The main challenges for Companies G and H are regulatory and administrative matters. As a respondent from Company G noted, “We must comply with MDR, the regulatory framework for medical devices. Regulatorily, it can be quite challenging; it requires a great deal of documentation, and it can take quite a long time to introduce new materials.” Under the MDR, a change to a single material requires a new 1-2-year test period and a new certification application, which strongly discourages circular innovation within these regulated sectors. Another challenge the companies face is finding circular materials compatible with the machines and processes. Company E (Home Decor) encountered problems with recycled plastics. The recycled material performed well in lab tests but could not be used in the existing injection-molding machines because it required different temperature or pressure settings. As a result, these recycled plastic materials are in demand for expensive new equipment upgrades, which puts the company in a new decision: “to invest or not invest”.

4.1.4 Performance Monitoring and Follow-Up

To evaluate the success of the material choice, measures are based on long-term corporate targets rather than short-term circularity metrics. Companies A, G, and K prioritize Scope 3 emissions related to purchased goods and services as their core performance metric. As Company A explained, “Scope 3 is where our products come in. And if you look at our total CO2 impact, well over 95% lies in Scope 3. Finding circular solutions and finding products with better environmental performance is absolutely the core focus for us.” A material change that does not significantly reduce Scope 3 CO2 emissions is, in general, classified as a “greenwashing” effort rather than a success. Companies B and C entrust their suppliers with annual visits and audits to check if the recycled material is actually being used. Company B specifically mentioned: *“We visit our sub-suppliers annually to follow up that they are actually doing what they said they were doing.”* This follow-up is necessary to prevent greenwashing and ensure the actor fulfills its obligations throughout the contract’s duration. Retail companies D and E conduct quarterly inspections of their “Material basket” by measuring the percentage of “preferred” materials (recycled, biobased, or organic) versus virgin materials, and report the progress to the board.

To present an integrated overview of the material selection strategies identified at the eleven companies, Table 2 summarizes the primary drivers, organizational roles, and implementation barriers. As shown in the table, the decision-making environment is characterized by high industry-specific friction, whereas the technical requirements serve as the final gatekeeper for circular objectives.

Table 2: Cross-Case Analysis of Material Selection Decision-Making

Company	Industry Category	Primary Decision Driver	Sustainability Role	Key Implementation Barrier
A	Logistics	Customer Demand/Pilot	Advisory	Return Infrastructure
B	Power systems manufacturing	Global Design Specs / LCA	Standard Setter	Global Scalability
C	Industrial	Internal CO2/Price Matrix	Tool Provider	Material Purity
D	Fashion	Brand Strategy	Strategic Guide	Fiber Degradation
E	Home decor	"Material Basket" Goals	Strategy Setter	Traceability/Paper Trail
F	Energy/Tech	Circular Indicators (CTI)	Monitoring	Regulatory (REACH)
G	MedTech	Safety / Climate Goals	Sust. Procurement	Regulation (MDR)
H	Defense	EU Regulation (RoHS)	Compliance	Ballistic Integrity
I	Heavy Vehicle	Safety / Modularity	Support	Market Scarcity
J	Steel	Executive Strategy	Visionary	High Price Premium
K	Automotive	CO2 Targets / SBTi	Technical Support	Material Impurities

The data obtained for research question 1 indicate that the strategic intent to transform toward circularity is high, but the material's circular potential is closely linked to technical and safety requirements. Even though the strategic alignment is clear, implementation can often be delayed by technical constraints or high economic costs. The tension between the company's environmental goals and industrial feasibility is the focus of the next section, which explores the specific trade-offs and economic pressures in this transition towards circularity.

4.2 Experienced Trade-offs in Material Choices

Throughout the interviews, circular material options, including new and redeveloped materials, involve many trade-offs among sustainability goals, cost-effectiveness, customer needs, and implementation feasibility. The respondents all agreed that circularity is an important strategy; however, they also noted that successful implementation will require assessing environmental costs alongside economic and operationally suitable solutions. The trade-offs associated with circular materials should be viewed as recurring issues rather than as separate decision-making events in establishing supply chains, developing products, or conducting procurement.

4.2.1 Circularity and Cost Efficiency

One of the most consistently reported trade-offs was between adopting circular materials and maintaining cost-efficiency. For instance, when describing the use of reused or regenerated resources, companies typically cite greater complexity or cost when transitioning from conventional virgin materials to circular ones.

Companies noted that procuring circular materials generally incurs additional costs due to supply limitations, processing requirements, or underdeveloped product ecosystems. Company D described this tension directly: “I would say it is somewhere between 5 and 15 percent perhaps, but you always have to balance what the customer is willing to pay against what you put into the product, because the worst thing you can do is produce something nobody wants to buy.” This creates a recurring conflict between achieving environmental objectives and maintaining product margins. Additionally, even if the recycled material offers clear environmental benefits, it may still not be used if doing so would substantially affect profitability or the final product's price.

Similarly, Company J described the scale of this premium directly: “There is a fairly significant price premium on these products; we are talking about a 25-30% price premium at present.” This price difference was identified as a major barrier to large-scale adoption, particularly in cost-sensitive applications. As the same respondent noted, adoption therefore tends to begin in premium product segments where customers are more willing to absorb higher costs.

However, some companies emphasized that adopting circular materials can also generate long-term economic benefits. Company C described the use of regenerated sealing materials, where production waste from suppliers is reused to manufacture new components. This approach not only reduced environmental impact but also lowered material costs by reducing waste. This example illustrates how circular material flows can simultaneously improve sustainability and cost-efficiency when properly integrated into production processes.

Despite such examples, the overall pattern suggests that short-term economic considerations often constrain the adoption of circular materials. Companies must justify circular material choices not only on environmental benefits but also on financial feasibility and long-term value creation.

4.2.2 Circularity and customer requirements

The interviewees identified customer requirements as both a driver and a constraint in adopting circular materials. While many customers increasingly request sustainable or circular solutions, respondents emphasized that customer willingness to accept cost increases or performance compromises remains limited.

Company D highlighted a clear gap between stated preferences and actual purchasing behavior: “I don't think our customer is ready to pay more just because it is a better material. It is much more about how this builds trust in us as a brand, and that customers, for that reason, become more inclined to accept a higher price.” While customers often express strong sustainability preferences, these preferences do not always translate into actual purchasing decisions when circular materials increase product costs. As a result, companies must carefully balance sustainability ambitions with customer price sensitivity.

At the same time, customer requirements were described as a major driver of the adoption of circular materials in industrial markets. Company A described how customer pressure could raise the bar rather than limit choices: “One of our largest customers, for example, in one of their procurements, the focus on sustainability was so strong that in the end very few suppliers could qualify, and price became completely irrelevant.” This has led companies to actively encourage suppliers to develop circular-material alternatives to remain competitive and meet customer expectations.

Company K explained that circular material requirements are often incorporated directly into supplier specifications. However, as the respondent observed, “My sense is that customers say they are willing to pay for sustainability to a greater extent than they are actually willing to pay for it”, a gap that shapes how ambitiously circular requirements can be set in practice. Suppliers sometimes cannot fully meet targets due to material availability constraints, requiring negotiation and compromise between circularity goals and practical feasibility.

In some cases, customer requirements also impose strict performance and reliability standards that limit the use of circular materials. Company H described how material choices are heavily constrained by performance and safety requirements, particularly in highly regulated industries. Even when circular materials are environmentally preferable, they cannot be adopted if they do not meet stringent performance standards.

4.2.3 Circularity against risk and performance

A major trade-off across multiple companies is the technical risks and performance uncertainties associated with circular materials. While recycled materials can offer significant environmental benefits, they may introduce variability in material properties, availability, and reliability.

Company K provided a clear example of this trade-off in the use of recycled metals. While recycled aluminum could be used successfully without compromising performance, recycled copper posed significant challenges due to its lower conductivity and increased variability. This created performance risks that limited the feasibility of adopting circular materials in certain applications. A similar dynamic was observed in textiles. Company D described the quality challenge directly: “When you recycle textiles, it is hard to get the same quality from recycled fibers. You shorten the fiber length, which means it might pill more or not hold the same stability in the garment.” Illustrating that performance variability in circular materials is not limited to industrial or technical applications but extends across sectors where material integrity is critical to the end product.

Company G explained that circular materials are difficult to incorporate into medical products: “When it comes to looking at entirely new materials, regarding recycled materials, we are currently very limited in what we can do from a safety and biocompatibility perspective, given that we produce medical devices.” Any variability in material properties could compromise product safety or regulatory compliance, restricting circular adoption largely to non-critical components such as packaging.

Company C also emphasized that the adoption of circular materials must be carefully evaluated against functional requirements. In some applications, regenerated materials can be used without affecting performance. In other cases, performance requirements make circular materials unsuitable, necessitating continued use of virgin materials.

Beyond technical performance, companies also highlighted supply chain risks associated with circular materials. Company H explained that circular materials often require extensive validation, testing, and certification to ensure performance equivalence with virgin materials. Company D described how its own certification requirements create an additional cost barrier: "We only accept third-party verified certificates as proof of recycled content. That makes it harder for us to reach our targets, but it is because we want to make sure that what we are buying actually is what it claims to be. The result is that things get considerably more expensive quite quickly." This validation process can be time-consuming and costly, creating additional barriers to adoption.

4.2.4 How circular material trade-offs are managed in practice

Companies described several mechanisms for managing trade-offs among circularity, cost efficiency, and performance. One key approach is cross-functional collaboration among procurement, R&D, and sustainability teams. Company K described how circular material decisions involve collaboration between multiple departments, including material experts, procurement teams, and sustainability specialists. This cross-functional approach allows companies to evaluate circular materials from both technical and economic perspectives.

Another important mechanism is supplier collaboration. Company C explained that adopting circular materials often requires close collaboration with suppliers to develop and validate new materials. Suppliers play a critical role in providing recycled materials and ensuring consistent material quality.

Companies also rely heavily on quantitative assessment tools, such as life-cycle assessments and carbon footprint analyses. Company F explained that circularity metrics and environmental impact assessments are used to evaluate the sustainability benefits of circular materials. These tools help companies compare circular and virgin materials and make informed decisions. Company K described how this translates into a practical prioritization logic, “We try to work systematically, we start with the ones that have large CO2 savings for a low cost or performance loss. When we have taken all of those, we will start looking at ones with a small extra cost for a reasonable CO2 saving.” This illustrates that trade-off management is not ad hoc but follows an implicit cost-efficiency logic in which environmental gains are pursued in order of their economic feasibility.

Pilot projects and gradual implementation were also common strategies. Rather than fully replacing virgin materials immediately, companies often introduce circular materials incrementally, starting with non-critical components. Company A described this approach: “We work a lot with experiments and pilots. The whole idea is, of course, to make the pilot customer very happy, but our idea is to make it a scalable service that we can apply to all customers who would want it.” This allows companies to reduce risk while gaining experience with integrating circular materials, before committing to broader supply chain changes.

4.3 Supply Chain Design Implications of Material Choices

The adoption of circular materials was consistently described as having significant implications for supply chain design. Rather than being isolated procurement decisions, circular material choices were shown to influence supplier selection, geographic sourcing strategies, reverse logistics capabilities, internal planning, and traceability systems. Across the interviews, circularity was associated with a transition from linear supply chain configurations toward more integrated, traceable, and regionally interconnected supply networks.

4.3.1 Sourcing and Supplier Base

A key consequence of adopting circular materials is the transformation of the supplier base. Several companies described how circular material integration requires sourcing from suppliers that can provide recycled, regenerated, or otherwise circular materials. This often introduces new actors into the supply chain, particularly recycling companies, material processors, and specialized suppliers capable of handling circular inputs.

Company I explained that adopting circular materials has led to increased collaboration with recycling partners and material recovery specialists. These suppliers play a critical role in providing secondary raw materials that can replace virgin materials in production. Company J described this dependency explicitly, “Fossil-free scrap, that is the gold of the future in our industry. We are very careful when signing a letter of intent with a customer to supply them with greener steel. We have to make sure the scrap comes back to us, because there will be a shortage of scrap in Sweden and the Nordics.” This creates a supply chain structure fundamentally different from traditional linear models, as material sourcing depends not only on extraction but on effective recovery and recycling systems.

In addition to introducing new supplier types, adopting circular materials also increases the importance of supplier capabilities and material traceability. Several respondents emphasized that not all suppliers can deliver recycled materials that meet required performance and quality standards. As a result, supplier selection increasingly depends on suppliers’ ability to provide circular materials with consistent quality, traceability, and environmental documentation. Company G described the expanded set of criteria now applied when evaluating new suppliers: "The supplier should ideally meet requirements such as being committed to Science Based Targets, being compliant with ethical sourcing depending on where in the world they are located, and being able to provide us with a product carbon footprint. Does the supplier have a decarbonization plan they can share with us? There are quite a few steps that need to be worked through to approve a new supplier, beyond price." It creates stronger dependencies between firms and suppliers, as companies must collaborate closely with suppliers to ensure reliable material supply and to validate circular material performance.

4.3.2 Network Design and Geographic Sourcing

Circular material choices also influenced the geographic structure of supply chains. In several cases, adopting circular materials encouraged greater regional sourcing, as recycled materials are often recovered and processed locally. It creates opportunities to shorten supply chains, reduce transportation distances, and improve supply chain resilience.

Company C described how sourcing recycled materials from European suppliers provided both environmental and operational benefits, including reduced transportation emissions and improved supply reliability. Company A framed the broader structural challenge this creates: “We are fundamentally designed to deliver products in one direction. What we are thinking a lot about is how the entire logistics system should better promote circularity with customers." Similarly, Company K explained that local recycling loops can reduce dependence on global raw material supply chains, which are often exposed to geopolitical risks and supply disruptions. By sourcing circular materials closer to production sites, companies can improve supply chain stability and reduce exposure to global supply chain volatility.

However, adopting circular materials also introduces new geographic constraints. Company E explained that circular materials may be available only in certain regions, creating challenges for globally distributed production networks. This requires companies to balance the benefits of local circular sourcing with the operational realities of global production systems. As a result, adopting circular materials may require adjustments to sourcing strategies or supplier networks to ensure material availability across different production locations.

In addition, companies described how adopting circular materials can influence supply chain planning and inventory strategies. When materials are sourced locally through recycling loops, lead times may be reduced, enabling more responsive supply chains and potentially reducing inventory requirements. Conversely, when circular materials are sourced from limited suppliers or emerging recycling markets, companies may face increased supply uncertainty, requiring more careful planning and supplier coordination.

4.3.3 Reverse Logistics and Material Recovery

Reverse logistics capabilities were identified as a critical enabler of circular material flows. Unlike traditional linear supply chains, which primarily focus on forward flows from suppliers to customers, circular supply chains require mechanisms to recover materials after use and reintegrate them into production.

Company J described how scrap steel is collected and reused as a key input in steel production, creating a closed-loop material system in which end-of-life products become a valuable resource rather than waste. The reverse flow of materials is essential for enabling circular material production and reducing dependence on virgin raw materials.

Company I explained that scrap materials and defective components are sorted and returned to recycling partners for processing and reuse in production. Consequently, it will require supply chains to incorporate processes for material recovery, sorting, and reintegration. Company K provided the most developed example of institutionalized reverse logistics: "We have worked for 70 years with return flows of our end-of-life components through remanufacturing.” In this system, customers receive a financial incentive to return worn components, which are then refurbished and resold, demonstrating that circular material recovery can become a stable business model when embedded in long-term customer relationships.

Company A also described reverse logistics systems that collect returned products and reintroduce them into inventory. While currently limited in scale, such systems demonstrate how reverse logistics capabilities can enable material reuse and support circular material flows.

These examples illustrate that adopting circular materials requires supply chains to expand beyond traditional forward logistics and incorporate reverse material flows. This fundamentally changes supply chain design by introducing new processes, relationships, and logistical requirements.

4.3.4 Inventory, Planning, and Traceability Implications

The adoption of circular materials was also found to increase supply chain complexity across planning, inventory management, and traceability. Unlike virgin materials, which are typically sourced through standardized supply chains, circular materials often require detailed tracking to verify their origin, composition, and sustainability attributes.

Company F explained that adopting circular materials requires enhanced traceability systems to ensure that recycled materials can be tracked through the supply chain and verified for sustainability reporting. Similarly, Company J emphasized the importance of traceability systems for ensuring that circular material content can be verified and communicated to customers. Company C described the operational depth this requires, “For steel, we want full traceability: which steelworks, which heat, which batch, delivery date. We want to trace the material back to its exact origin. And it is also a requirement now with the tariff restrictions coming in.” Traceability is not merely a sustainability reporting tool but increasingly a legal and commercial necessity embedded in procurement practice.

Adopting circular materials also introduces new planning challenges. Companies must manage both virgin and recycled material streams, which may have different availability patterns, lead times, and quality characteristics. Company J said, “We will be forced to stock three identical grades and thicknesses, just in different climate specifications. It is a challenge we have only just dipped our toes into. I think it can become very, very complex for our industry to manage.” This increases planning complexity and requires closer coordination between procurement, production, and logistics functions.

In addition, companies noted that adopting circular materials may require additional quality control and material-handling processes. Materials recovered through recycling or reuse must often be inspected, sorted, and processed before they can be reintroduced into the production process. This creates additional operational requirements and reinforces the need for integrated supply chain coordination.

5. Analysis and Discussion

This chapter presents the analysis and discussion of the empirical findings in relation to the research questions and theoretical framework. Here, the research questions are answered by analyzing how circular material selection decisions are made, what trade-offs emerge, and how these decisions influence supply chain design. The analysis interprets the empirical findings through the theoretical perspectives and the conceptual framework (Figure 1), providing a structured explanation of circular material selection as an organizational and supply-chain decision-making process.

5.1 Analysis of Decision-Making Processes

Circular material selection is a structured organizational decision-making process shaped by external drivers, organizational capabilities, and operational feasibility constraints. Rather than an isolated sustainability decision, it is a constrained process embedded within existing operational structures and supply chain systems, as illustrated by the conceptual framework in Figure 1.

A central finding is the existence of a structured, multi-stage decision-making process covering material identification, technical validation, cross-functional evaluation, governance approval, and pilot implementation. This sequential process reflects bounded rationality theory, which posits that organizations evaluate alternatives within operational and informational constraints rather than optimizing across all available options simultaneously (Bendoly et al., 2006; Croson et al., 2013). Technical feasibility and safety requirements function as the primary decision thresholds throughout this process. Companies in highly regulated industries such as MedTech and heavy vehicles rejected circular materials immediately when they failed to meet safety or performance requirements, regardless of environmental benefits. This is consistent with Wu and Pagell's (2011) argument that sustainability initiatives are pursued only after operational feasibility is secured, indicating that circular material selection is governed by feasibility-based logic rather than environmental optimization alone.

Circular material selection also emerges from cross-functional processes involving procurement, engineering, sustainability, and executive management. Sustainable supply chain management theory emphasizes that sustainability-related decisions involve balancing competing objectives across organizational functions (Carter & Rogers, 2008; Seuring & Müller, 2008), and that this tension is clearly visible. Procurement departments prioritized cost efficiency and supplier reliability, engineering departments prioritized technical performance and operational compatibility, and sustainability departments primarily provided advisory input rather than decision-making authority. This organizational structure reflects the goal conflict perspective described by Pagell and Shevchenko (2014), in which sustainability decisions emerge from negotiations among competing organizational priorities rather than from independent environmental decision-making. The practical implication is that the choice of circular materials depends heavily on whether engineers and procurement teams consider them workable, rather than solely on the strength of the sustainability case. External drivers were consistently identified as critical triggers for circular material selection decisions. Regulatory requirements, corporate sustainability targets, and customer expectations all played a role in initiating material evaluation processes, supporting sustainable supply chain management theory regarding the influence of external institutional pressures (Carter & Rogers, 2008; Seuring & Müller, 2008). Companies in regulated sectors such as MedTech and defense reported that frameworks such as REACH and MDR directly required material substitution, thereby transforming circular material selection from a voluntary initiative into a compliance requirement. Executive-level sustainability mandates had a similar effect, as seen in Company K's fossil-free material targets and Company J's transition to green steel, giving sustainability organizational weight that internal advocacy alone rarely achieves.

Organizational capabilities played a critical role in determining implementation feasibility, which supports the resource-based view of the firm (Barney, 1991; Teece et al., 1997). Several companies found that circular materials that met sustainability and technical requirements could still not be adopted because existing production equipment was incompatible, or supplier traceability systems were insufficiently developed. This points to a structural gap where adopting circular materials requires building new organizational capabilities, not just making new procurement decisions. It also helps explain why adoption rates vary so significantly between firms operating under similar external conditions, since capability development requires time and investment that not all organizations are equally positioned to make.

Material traceability and data transparency also emerged as central factors in circular material decision-making. Companies frequently rejected circular materials due to insufficient traceability or uncertainty around material composition and origin. Incomplete material information increases operational risk and reduces implementation feasibility (Yuan, 2025; Zhang & Seuring, 2024), as was directly evident in practice. Material selection decisions are therefore shaped not only by physical performance characteristics but also by the availability and reliability of supporting data, underscoring the importance of organizational traceability systems in enabling circular material adoption.

Path dependency also shapes circular material selection in ways that are worth highlighting. Once materials are integrated into production with qualified suppliers, validated specifications, and regulatory approvals in place, the cost and effort of switching grow substantially. Companies reported that implementing circular materials often required developing new supplier relationships, modifying production processes, and building new traceability systems. Supply chain design theory emphasizes that material and sourcing decisions create long-term structural commitments (Simchi-Levi et al., 2008), and Montabon et al. (2016) argue that the implementation of the circular economy depends on organizational and supply chain compatibility rather than on theoretical environmental superiority. Companies that delay circular adoption are therefore not just postponing an environmental benefit. They are reinforcing a production structure based on conventional materials that becomes progressively harder to shift away from.

Overall, circular material selection is a constrained organizational decision-making process shaped by external drivers, organizational capabilities, and operational feasibility requirements. Sustainability considerations are integrated into decision-making but remain contingent on technical feasibility, regulatory compliance, and operational compatibility, consistent with SSCM theory, decision-making theory, and the resource-based view (Carter & Rogers, 2008; Wu & Pagell, 2011). This supports the conceptual framework in Figure 1, which illustrates how external drivers, organizational decision-making processes, and capability constraints collectively determine circular material selection outcomes and supply chain implications.

5.2 Analysis of Trade-offs in Circular Material Choices

Trade-offs are a central mechanism shaping circular material selection decisions and sit between organizational decision-making processes and supply chain outcomes, as illustrated in the conceptual framework (Figure 1). Conflicts between sustainability objectives, operational feasibility, cost efficiency, technical performance, and supply chain stability consistently characterize circular material selection. This is consistent with sustainable supply chain management theory, which argues that sustainability initiatives involve balancing environmental, economic, and operational objectives rather than optimizing a single performance dimension (Carter & Rogers, 2008; Pagell & Shevchenko, 2014).

The most prominent trade-off across the cases was between sustainability objectives and technical performance requirements. Circular materials, particularly recycled plastics and metals, often exhibit inconsistent mechanical properties, reduced durability, and lower processability compared to virgin materials. Recycled copper and plastic materials introduced performance variability and operational risks in safety-critical applications, thereby directly supporting material selection theory, which argues that performance characteristics are primary selection criteria that constrain sustainability implementation (Wu & Pagell, 2011; Pagell & Shevchenko, 2014). It also reinforces Wu and Pagell's (2011) point that sustainability improvements are pursued only when they do not compromise operational feasibility, demonstrating that technical performance functions as a hard constraint rather than a negotiable factor.

Cost-related trade-offs were also consistently identified as a major barrier. Companies reported that circular materials generally involved higher procurement and processing costs and greater operational complexity than conventional alternatives. These higher costs were largely attributed to limited supplier availability, immature recycling infrastructure, and additional traceability and certification requirements. This aligns with SSCM literature, which highlights that sustainability initiatives often entail short-term cost increases that need to be weighed against long-term environmental and strategic benefits (Seuring & Müller, 2008). From a resource-based view perspective, these cost trade-offs also reflect the need for firms to develop new organizational capabilities and infrastructure to support circular material integration (Barney, 1991; Teece et al., 1997), meaning that companies without those capabilities face higher implementation costs, further reducing the feasibility of adoption.

Supply chain risk and reliability trade-offs also emerged as critical factors. Companies frequently raised concerns about supplier reliability, material availability, and quality consistency when sourcing circular materials. Recycled materials were often available only in limited quantities or exhibited inconsistent quality due to variability in input material streams. Supply chain risk management theory emphasizes that supply chain decisions prioritize reliability and continuity to avoid operational disruptions (Simchi-Levi et al., 2008). Circular materials, particularly those sourced from emerging or specialized recycling suppliers, introduced considerably more uncertainty than those sourced from established conventional suppliers. This increased risk often limited the adoption of circular materials even when the environmental benefits were clear (Guide & Van Wassenhove, 2009).

Traceability and regulatory compliance trade-offs also emerged as significant barriers. Companies reported that circular materials often lacked sufficient documentation to verify their origins, compositions, and compliance with regulatory standards. In regulated industries like MedTech and defense, this created direct compliance risks, as material traceability and certification are mandatory. Traceability systems are a critical enabling capability for implementing circular materials (Guide & Van Wassenhove, 2009; Zhang & Seuring, 2024), and without adequate traceability infrastructure, circular materials introduce operational and regulatory uncertainty that outweighs their environmental advantages regardless of how strong the sustainability case may be.

Rather than accepting these trade-offs as fixed barriers, companies actively managed them through organizational mechanisms. Pilot testing, supplier collaboration, and incremental implementation were the most common strategies used to reduce performance and operational risks when introducing circular materials. This is consistent with dynamic capability theory, which emphasizes that firms develop new capabilities over time to adapt to changing operational and environmental requirements (Teece et al., 1997). Rather than immediately replacing conventional materials, companies tested circular alternatives gradually, reducing risk and building organizational experience before committing to broader supply chain changes.

Trade-offs, therefore, represent a fundamental constraint shaping circular material selection decisions. As the conceptual framework (Figure 1) illustrates, they mediate the relationship between organizational decision-making and supply chain outcomes, determining whether circular materials can be successfully implemented. The adoption of circular materials is determined not only by sustainability objectives but also by the organization's ability to balance environmental, operational, and economic constraints within complex supply chain systems.

5.3 Analysis of Supply Chain Design Impacts

Circular material selection decisions carry significant structural implications for supply chain design, as the final stage of the conceptual framework (Figure 1) captures. Across the companies studied, adopting circular materials was consistently associated with changes in supplier networks, sourcing strategies, logistics processes, and traceability systems. Supply chain design theory emphasizes that material and sourcing decisions directly shape supply chain configuration, supplier relationships, and operational structures (Simchi-Levi et al., 2008), and that is clearly visible here. Circular material selection is not an isolated procurement decision but a structural driver of supply chain transformation.

A key finding is that adopting circular materials requires establishing new supplier relationships and sourcing strategies. Companies reported that circular materials were often sourced from specialized recycling firms or suppliers outside their traditional networks. Strategic sourcing theory emphasizes that material selection decisions directly influence supplier selection and supply chain configuration (Genovese et al., 2017), and this played out in practice as companies had to identify new suppliers with specialized capabilities in material recovery, recycling, or circular material processing. Circular material selection, therefore, reshapes supply chain networks not just by changing what is sourced but by introducing entirely new types of supply chain actors.

The development of reverse logistics processes also emerged as a key implication for supply chain design. Several companies implemented material recovery systems to collect production scrap, returned products, or excess materials for reintegration into production. Closed-loop supply chain theory emphasizes the integration of forward and reverse material flows as a core characteristic of circular supply chains (Guide & Van Wassenhove, 2009), and the cases here show that circular material selection cannot be separated from this structural requirement. Building reverse logistics capability is not optional; it is a prerequisite for making circular material flows work in practice.

The development of a traceability system was another critical implication of supply chain design. Companies reported implementing enhanced material-tracking and documentation systems to verify the origin, composition, and regulatory compliance of materials. Traceability systems are essential for managing circular material flows and ensuring compliance with regulatory and quality requirements (Farooque et al., 2019; Yuan, 2025). Without them, circular materials introduce uncertainty that makes adoption impractical, regardless of their environmental benefits. Circular material selection, therefore, requires not only new sourcing strategies but also investment in information infrastructure.

The adoption of circular materials also influenced geographic sourcing strategies. Several companies moved toward more regional sourcing to reduce supply chain complexity, improve traceability, and lower transportation emissions. Sourcing location decisions influence supply chain efficiency, risk, and sustainability performance (Simchi-Levi et al., 2008), and regional sourcing improves supply chain visibility while reducing reliance on complex global supply chains. For some companies, this was a deliberate strategic choice, while for others it was a practical consequence of where recycled materials were available.

Closer supplier collaboration was also required to make the adoption of circular materials work. Companies reported increased supplier engagement, joint material testing, and collaborative process development to ensure compatibility with circular materials. Supplier collaboration and integration are critical for managing supply chain complexity and driving innovation (Ketokivi & Choi, 2014), and this was particularly evident in cases where circular materials required extensive qualification processes or where suppliers needed to develop new capabilities alongside the buying company.

Taken together, these findings show that circular material selection functions as a structural driver of supply chain transformation, as the conceptual framework (Figure 1) illustrates. Adopting circular materials reshapes supplier networks, material flows, and operational processes, requiring organizations to fundamentally rethink sourcing strategies, logistics systems, and supplier relationships. Circular material selection is therefore not a material substitution decision but a strategic supply chain design decision.

It is also worth noting that this transformation tends to occur gradually rather than all at once. Companies reported incrementally integrating circular materials, building new supplier relationships, and developing traceability systems over time. Path dependency theory supports this, emphasizing that supply chain structures evolve incrementally due to existing operational constraints and organizational routines (Ketokivi & Choi, 2014). Circular supply chain transformation is therefore a process of progressive adaptation, which is why the pilot-and-iterate loop in the conceptual framework (Figure 1) is an important part of how these changes unfold in practice.

5.4 Synthesis and Integration with the Conceptual Framework

The findings across all participating organizations show a consistent pattern in how circular material selection decisions emerge and influence supply chain design, which confirms the sequential logic of the conceptual framework (Figure 1). External drivers initiate circular material evaluation; organizational capabilities and feasibility constraints determine what is viable; trade-offs shape implementation decisions; and supply chain structures are subsequently adapted to support circular material integration. The framework captures well that circular material selection is mediated by organizational and supply chain constraints rather than driven solely by environmental objectives.

External drivers consistently served as the primary triggers for circular material selection decisions. Regulatory requirements, corporate sustainability targets, and customer demands were what set the process in motion across all companies. Sustainable supply chain management theory emphasizes that external institutional pressures significantly influence organizational supply chain decisions (Carter & Rogers, 2008; Seuring & Müller, 2008), and this was clearly the case here. However, external drivers alone do not guarantee implementation. They initiate the process, but whether a material is adopted depends on what happens at subsequent stages of the framework.

The constraint filter captures the central mechanism governing what gets through. Rather than entering a balanced evaluation of all criteria simultaneously, materials had to clear three sequential gates covering technical feasibility, regulatory compliance, and organizational capability before sustainability was evaluated. This reflects a bounded-rationality perspective, which suggests that organizational decisions are constrained by operational feasibility and informational limitations rather than by theoretical optimality (Bendoly et al., 2006; Wu & Pagell, 2011). Organizational capabilities, including production infrastructure, supplier capabilities, and traceability systems, played a critical role in determining feasibility and in supporting the resource-based view (Barney, 1991; Teece et al., 1997).

Trade-offs then emerged as the key mediating mechanism between the constraint filter and supply chain outcomes. For materials that passed the constraint filter, companies still had to balance sustainability objectives against technical performance, cost efficiency, supply chain reliability, and regulatory compliance. This is consistent with SSCM theory, which emphasizes that sustainability implementation requires navigating environmental, operational, and economic objectives simultaneously (Pagell & Shevchenko, 2014). Trade-offs shaped implementation decisions in practice, reinforcing that adopting circular materials depends on ensuring compatibility with existing operational and supply chain requirements rather than simply making an environmental case.

The supply chain design implications then followed from these decisions. Adopting circular materials required organizations to establish new supplier relationships, implement traceability systems, integrate reverse logistics processes, and adapt sourcing strategies. Supply chain design theory emphasizes that sourcing and material decisions shape supply chain structure and operational configuration (Simchi-Levi et al., 2008), and the structural changes observed here demonstrate that circular material selection is a key mechanism through which organizations begin transitioning from linear to circular supply chain models.

The synthesis shows that the conceptual framework (Figure 1) holds up well as an explanatory model of how circular material selection decisions emerge and influence supply chain design. The sequential relationships between external drivers, the constraint filter, trade-off evaluation, and supply chain transformation were all clearly visible across the cases. Circular material selection is not a one-off procurement decision but an evolving organizational process, and the pilot-and-iterate loop in the framework reflects how companies, in practice, move incrementally through that process rather than transforming their supply chains all at once.

6. Conclusions

This chapter presents the study's conclusions by addressing the research questions using the empirical findings and analysis. Drawing on the conceptual framework (Figure 1) and the theoretical foundation, this chapter summarizes how circular material selection decisions are made, what trade-offs emerge, and how these decisions influence supply chain design.

6.1 Summary of Findings

This study aimed to understand how circular material selection decisions are made within supply chains, what trade-offs emerge in this process, and how these decisions influence supply chain design. By analyzing empirical data from multiple industrial organizations and interpreting the findings using established supply chain management theory and the conceptual framework (Figure 1), this study provides a structured explanation of circular material selection as an organizational and supply chain decision-making process.

How are decisions regarding material selection made in circular supply chains (e.g, recycled, locally sourced, or globally sourced materials)?
Circular material selection decisions emerge through structured organizational decision-making processes shaped by external drivers, technical feasibility constraints, and organizational capabilities. Rather than being driven solely by sustainability objectives, circular material selection is guided by feasibility-based evaluation processes that involve technical validation, cross-functional coordination, and governance approval. This confirms that sustainability considerations are integrated into decision-making but remain conditional on operational compatibility, regulatory compliance, and organizational capabilities.

What trade-offs emerge between sustainability objectives, cost efficiency, and customer requirements?
The findings also highlight that selecting circular materials involves significant trade-offs among sustainability objectives and operational, economic, and supply chain performance requirements. Companies must balance environmental benefits against technical feasibility, cost efficiency, supply chain reliability, and regulatory compliance. These trade-offs function as practical constraints that determine whether circular materials can be successfully implemented. As a result, the adoption of circular materials is shaped by organizations' ability to manage and resolve these competing performance objectives.

In what ways does material selection influence supply chain design?

Furthermore, circular material selection decisions have significant implications for supply chain design. Adopting circular materials requires organizations to establish new supplier relationships, implement traceability systems, integrate reverse logistics processes, and adapt sourcing strategies. These changes illustrate that circular material selection is not merely a procurement decision but a strategic supply chain design decision that influences supply chain configuration and operational structure.

Overall, the conceptual framework illustrates how circular material selection decisions emerge and evolve. External drivers initiate circular material evaluation; the constraint filter screens materials through sequential feasibility gates before sustainability is even considered; trade-offs mediate implementation decisions for materials that pass; and supply chain structures are subsequently adapted to support the integration of circular materials. Circular material selection is therefore not a one-time procurement decision, but an evolving organizational process shaped by feasibility, capability, and structural adaptation.

6.2 Contributions of the Study

This study contributes to supply chain management and circular economy literature by providing an empirically grounded explanation of how circular material selection decisions emerge and influence supply chain design. While existing research has emphasized the environmental importance of adopting circular materials, less attention has been paid to the organizational decision-making processes and supply chain constraints that shape these decisions in practice. By examining circular material selection as an organizational and supply chain decision-making process, this study provides a more nuanced understanding of how circular economy principles are operationalized within real-world supply chain contexts.

In practice, the adoption of circular materials is governed by a constraint filter that requires materials to clear sequential feasibility gates before sustainability is evaluated. This extends sustainable supply chain management (SSCM) literature, which highlights the integration of environmental considerations into supply chain decisions (Carter & Rogers, 2008; Seuring & Müller, 2008), by demonstrating that sustainability considerations are integrated conditionally rather than independently. Circular material selection is shaped by technical feasibility, regulatory compliance, and organizational capability, echoing prior arguments that the implementation of sustainability depends on operational feasibility and organizational constraints (Wu & Pagell, 2011). This provides empirical evidence explaining how sustainability objectives are translated into operational decisions within supply chains and introduces the constraint filter as a conceptual mechanism that prior frameworks have not made explicit.

The study also contributes to supply chain design theory by demonstrating that circular material selection functions as a structural driver of supply chain transformation. Material selection decisions were found to influence supplier relationships, sourcing strategies, traceability systems, and reverse logistics integration. This highlights the role of material selection as a mechanism for transitioning supply chains from linear to circular configurations, extending existing supply chain design theory that emphasizes the structural implications of sourcing and material decisions (Simchi-Levi et al., 2008).

Furthermore, this study contributes to circular economy and supply chain management literature by developing and empirically supporting the conceptual framework (Figure 1). The framework integrates external drivers, organizational decision-making processes, trade-offs, and the impacts of supply chain design into a coherent explanatory model. By explicitly linking organizational decision-making processes with supply chain structural outcomes, the framework addresses a gap in existing literature, which has often focused on circular economy principles at a conceptual level without fully explaining the organizational and operational mechanisms that shape implementation.

Overall, this study advances theoretical understanding by demonstrating that circular material selection is not solely an environmental decision, but a constrained organizational and supply chain design process shaped by feasibility considerations, organizational capabilities, and supply chain structure. This provides a more comprehensive explanation of how circular economy principles are implemented within supply chains and how material selection decisions contribute to supply chain transformation.

6.3 Limitations

This study should be interpreted in light of several methodological and empirical limitations. The qualitative research approach enabled an in-depth understanding of circular material selection decision-making and supply chain implications across multiple sectors, including MedTech, automotive, steel, and defense. While the inclusion of organizations from different sectors strengthens the relevance and transferability of the findings, the limited number of participating companies limits the ability to fully generalize the results to all organizational or supply chain contexts. The findings should therefore be understood as analytically generalizable rather than statistically representative.

The study primarily reflects the perspective of focal firms responsible for material selection and supply chain decisions. Circular material selection involves interactions with multiple supply chain actors, including suppliers, recyclers, and logistics providers, whose perspectives were not examined in the same depth. As a result, the findings provide a more detailed understanding of internal organizational decision-making processes than of inter-organizational coordination across supply chain tiers.

In addition, the adoption of circular materials and the transformation of the circular supply chain are ongoing, evolving processes influenced by technological development, regulatory changes, and the development of organizational capabilities. The findings, therefore, reflect current organizational practices rather than long-term implementation outcomes.

Despite these limitations, the study provides valuable insights into how circular material selection decisions are made across sectors and how they influence supply chain design, thereby contributing to both theory and practice.

6.4 Suggestions for Future Research

While this study provides an exploratory understanding of how circular material selection decisions are made and how they influence supply chain design, several areas remain relevant for future research.

Future studies may adopt a longitudinal perspective to examine how circular material strategies evolve, particularly from pilot implementation to full-scale supply chain integration. Such studies may provide a deeper understanding of how organizational capabilities, supplier relationships, and decision structures develop throughout the transition process.

In addition, future research may explore circular material selection from a supplier perspective. Since supplier capabilities and traceability systems emerged as critical factors in this study, further research could help clarify how suppliers manage material verification, quality consistency, and collaboration requirements.

Further research may also expand the findings through quantitative studies involving a larger sample of organizations. This may support broader validation of the identified decision-making patterns and trade-offs across industrial contexts.

Finally, given the importance of traceability identified in the empirical findings, future research may investigate the role of digital traceability systems and digital product passports in enabling circular material flows and improving supply chain transparency.

7. Recommendations

This chapter presents practical recommendations based on the study's analysis. Circular material selection is not an isolated procurement decision but a cross-functional, strategic process that involves technical, economic, and sustainability considerations. The following recommendations are intended for organizations seeking to strengthen the implementation of circular materials in their supply chains.

One of the clearest patterns across the companies studied is that circular material decisions involve multiple functions simultaneously, covering procurement, engineering, sustainability, and management. Without structured collaboration between these functions, decisions tend to default to whichever department holds the most authority, which, in most cases, means technical and commercial priorities dominate. More formalized cross-functional decision-making structures could help organizations better align technical feasibility, cost efficiency, and sustainability objectives, while also making trade-off assessments more transparent.

Several companies also described challenges in comparing circular and conventional materials across dimensions like technical performance, cost, environmental impact, and supply risk. A more standardized internal evaluation framework would make these comparisons more consistent and easier to justify across organizational functions. Without such a framework, material decisions tend to be made on a case-by-case basis with no clear benchmark, making it harder to build on experience over time.

Supplier collaboration and traceability also stand out as areas where investment pays off. Long-term supplier relationships improve the consistency of material quality and make it easier to verify recycled content and compliance requirements. Traceability systems are increasingly a practical necessity rather than just a reporting tool, particularly as regulatory requirements around material documentation continue to tighten.

Introducing circular materials gradually through pilot projects, rather than full-scale replacement, is another approach that has worked well across multiple companies. Piloting reduces operational risk, allows compatibility issues to be identified early, and builds organizational experience before committing to broader supply chain changes.

Finally, short-term cost efficiency repeatedly emerged as a barrier that slowed or blocked circular adoption even when the long-term case was strong. Aligning internal performance metrics with long-term circularity goals, for example, by integrating sustainability-related KPIs alongside cost targets, could help shift decision-making toward a more balanced assessment of value over time.

Successful circular material implementation ultimately requires more than substituting one material for another. It depends on organizational coordination, supplier integration, and strategic alignment across the supply chain.

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Appendix A

Interview guide

Focus area 1	**RQ 1: How are decisions about material choices (e.g., recycled vs. local) made in circular flows** **Would get very different answers depending on whom we talk to in an organization.**
Decision process & criteria	Can you describe, step by step, how a decision about a new material (e.g., switching to recycled, bio-based, or locally sourced) is initiated and made in your organization? What are the primary criteria you use when evaluating materials in a circular flow (e.g., traceability, purity, availability, lifespan)? How do you **quantify** the circular potential or sustainability value of a material?
Involved stakeholders	Which departments/roles are involved in material selection decisions, and what role do they play (e.g., purchasing, design, R&D, sustainability manager)? How are decisions communicated and anchored upward in management?
Challenges	What are the biggest operational or technical challenges you face when implementing material choices that promote circularity (e.g., quality assurance of recycled materials)?

Measurement	How do you follow up and measure the impact of the material choice on the circular flow after implementation?

Focus area 2	RQ 2: What trade-offs are perceived between sustainability, cost-efficiency, and customer requirements
Sustainability vs. cost	Can you give a concrete example of when you had to choose between a more expensive, more sustainable material and a cheaper, less sustainable one? How was that decision made? How big a **cost premium** are you willing to accept for a material with significant sustainability benefits? What internal incentives or barriers exist when choosing cost-efficient vs. sustainable solutions?
Sustainability vs. customer requirements	Have you experienced that customer requirements (e.g., performance, aesthetics, price) have directly limited your ability to choose a more circular material? How did you handle it? How do you educate your customers about the value of sustainable material choices, and how do you measure customer acceptance of these materials? Perceived vs. actual value: Is there a gap between what customers say they want (sustainability) and what they are actually willing to pay for? How do you strategically navigate that gap?

Prioritization & frameworks	If you are forced to prioritize, which of these three factors (sustainability, cost, customer requirements) tends to weigh the most in your material selection decisions, and why? Do you have an internal framework or matrix to assess and manage these trade-offs objectively?

Focus area 3	**RQ 3: How circular material choices affect the overall strategy for Supply Chain Design**
Logistics & network design	In what way has the choice of recycled material (e.g., dependence on return flows) or locally sourced material changed your logistics structure (e.g., transport routes, warehousing points, inbound flows)? How do you integrate reverse logistics into your Supply Chain Design as a direct response to your material choices (e.g., to get your own products back for recycling)?
Supplier relationships	What new types of partnerships (e.g., with recycling companies, local producers) have you needed to establish as a result of your circular material choices? What requirements do you place on your suppliers regarding traceability and certifications for circular materials?
Future Strategy	How will your material choices strategically impact your Supply Chain Design over the next five years (e.g., relocation of production, increased automation of sorting)?

	How do you ensure that your material strategy is aligned with the company’s overall business strategy (e.g., product-as-a-service models)?

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