Supply Chain Management: an International J

Blockchain as Information Processing: Experiences in Recycling Chains

Journal:	*Supply Chain Management: an International Journal*
Manuscript ID	SCM-09-2025-0958.R2
Manuscript Type:	Original Manuscript
Keywords:	Recycling, Case Studies, Sustainability, Information systems

Blockchain as Information Processing: Experiences in Recycling Chains

Shenghao Xie
Shenghao.Xie@liverpool.ac.uk
Liverpool Management School, University of Liverpool, Liverpool, UK

Yu Gong*
y.gong@soton.ac.uk
University of Southampton Business School, University of Southampton, Southampton, UK

Martin Kunc
m.h.kunc@soton.ac.uk
University of Southampton Business School, University of Southampton, Southampton, UK

Steve New
steve.new@sbs.ox.ac.uk
Saïd Business School, University of Oxford, Oxford, UK

Corresponding author*: Yu Gong (y.gong@soton.ac.uk)

Blockchain as Information Processing: Experiences in Recycling Chains

Abstract

Purpose: Blockchain is often claimed to have significant potential for tackling recycling chains' challenges, particularly in facilitating information processing. However, such claims are often based on hypothetical, conceptual arguments. This study aims to explore how focal companies employ blockchain to address information processing needs in the recycling chain.

Design/methodology approach: The paper contains in-depth case studies exploring three pioneer blockchain applications in multi-tier recycling chains.

Findings: We found that blockchain offers four distinct information processing capabilities: transparency, immutability, integration, and trust. These capabilities are instrumental in addressing the specific information processing needs at the levels of firm, supply chain, and industry. However, the findings also suggest that blockchain-enabled mechanisms do not, by themselves, resolve all information processing needs in recycling chains. Instead, the application should account for functional, contextual, and systemic fit.

Originality/value: By critically exploring pioneer blockchain applications, we move beyond prevailing views of blockchain as an information processing tool by situating its role within the multi-level information processing needs of recycling chains. Rather than conceiving blockchain applications as mechanically matched to these needs, we propose a more nuanced conceptualization of fitting mechanisms, showing that information processing fit unfolds through functional, contextual, and systemic pathways operating across multiple levels.

Keywords: Blockchain technology, recycling, sustainable supply chain, information processing

Paper type: Research paper

1. Introduction

It is widely accepted that human civilization needs to shift its fundamental economic model. Modern industrial society is constructed upon an unsustainable linear approach (take–make–use–destroy); by contrast, companies are faced with an urgent need to shift to a circular economy (Ratsimandresy and Miemczyk, 2024). Beyond the early focus on the 3Rs (Reduce, Reuse, and Recycle), recent circular economy thinking advances the “10R framework” (European Commission, 2024), which emphasizes upstream interventions and product life extension to retain value across the product lifecycle.

Recycling is essential to a circular economy; yet daunting challenges persist (Ratsimandresy and Miemczyk, 2024; Zhang *et al.*, 2021). The World Economic Forum reported that, out of the 40 million tons of plastic waste generated in the US in 2021, only 5-6% was successfully recycled[1]. One of the most profound challenges lies in information processing along the recycling chain (Galbraith, 1974; Srinivasan and Swink, 2018), particularly in collecting reliable data, verifying their accuracy, and maintaining transparency to meet regulatory and market expectations. Misleading corporate recycling claims illustrate these challenges. For example, H&M’s “Conscious Choice” collection faced a greenwashing lawsuit for overstating its recycling benefits, and then withdrew its environmental-scoring tools[2], revealing data transparency issues for information processing. Such concerns are compounded by recycled materials often costing more than virgin alternatives and the ease with which recyclers can mislabel mixed-content products as “recycled” due to a lack of reliable information (Xie *et al.*, 2023). Moreover, regulators are tightening requirements on product lifecycle data disclosure. The EU’s Eco-design for Sustainable Products Regulation, for example, has introduced the Digital Product Passport (Deloitte, 2024), which mandates integrated data capture, chain-of-custody verification, and secure information sharing across recycling and reuse stages (Chaudhuri *et al.*, 2025), further highlighting the critical importance of robust information processing.

These information processing challenges largely arise from a lack of reliable and transparent information, which can be amplified in a multi-tier context as recycling chains often involve multiple actors across dispersed tiers (Tachizawa and Wong, 2014; Wilhelm *et al.*, 2016), and fragmented information makes it difficult to establish a complete chain of custody (Xie *et al.*, 2023). Blockchain technology (BCT) has been promoted as an effective information processing

---

[1] See https://www.weforum.org/stories/2022/06/recycling-global-statistics-facts-plastic-paper/ (accessed by 11 Dec, 2024).

[2] See https://www.reuters.com/legal/legalindustry/guidance-sustainable-claims-after-dismissal-hm-greenwashing-class-action-2023-06-02/ (accessed 17 Aug. 2025).

tool (Martinez *et al.*, 2019; Tuladhar *et al.*, 2024), which may potentially address the information processing challenges in recycling chains. BCT is seen as offering transparency and reliability so that recycling information can be tracked throughout its lifecycle (Saberi *et al.*, 2019). Through the decentralized means of sharing information, it is also expected to enhance inter-organizational trust (Brookbanks and Parry, 2022). Furthermore, BCT can strengthen information processing in recycling chains by using smart contracts to automate transactions (Gregory *et al.*, 2024), thereby reducing manual checks, speeding up transactions, and ensuring consistent rule enforcement across recycling activities.

Previous research suggests that more complex information processing challenges are often accompanied by greater uncertainties and higher information processing needs (Flynn *et al.*, 2016; Galbraith, 1974), which, in turn, require stronger processing capabilities (Srinivasan and Swink, 2018). However, much of the current discussion on BCT as an information processing tool remains conceptual (Baralla *et al.*, 2023; Bhatia and Gangwani, 2025), focusing mainly on its technical features and potential applications, while overlooking the highly complex and multi-tier structural characteristics of recycling chains (Xie *et al.*, 2023). In particular, BCT applications in recycling reveal a series of barriers that extend beyond the intra-organizational level, such as limited stakeholder willingness, process opacity, and difficulties in data coordination (Gong *et al.*, 2022; Saberi *et al.*, 2019; Xie *et al.*, 2023). These complexities not only constrain BCT's practical implementation but also highlight the importance of linking its application to multidimensional information processing needs.

Existing studies also suggest that either "enhancing technological capabilities" or "reducing uncertainties" may improve information processing fit (Bensaou and Venkatraman, 1995; Busse *et al.*, 2017; Hamann-Lohmer *et al.*, 2023). However, BCT itself cannot automatically lead to the fit; rather, the application depends on how it is embedded within recycling chains and how the underlying information processing mechanisms unfold in practice. Therefore, we aim to answer the following research question: *How can BCT applications help focal companies to meet information processing needs in recycling chains?*

To answer the question, we adopt a multiple-case study approach of three pioneer cases that have applied BCT in their recycling chains. Our theoretical framing draws on Organizational Information Processing Theory (OIPT) (Galbraith, 1974). This lens is well-suited to the recycling chain context which is characterized by information asymmetry, process uncertainty, and fragmented coordination (Pagell *et al.*, 2007; Xie *et al.*, 2023). It enables us to examine how real-world applications configure BCT-enabled information processing capabilities to meet these specific needs. The findings show that BCT offers four distinct information processing capabilities—transparency, immutability, integration, and trust—that help meet information processing needs at the firm, supply chain, and industry levels. Moreover, the application should focus on aligning these capabilities with the mechanisms of functional, contextual, and systemic fit.

The research makes the following key contributions to the existing literatures. First, we extend OIPT beyond its traditional intra organization views (Galbraith, 1974) to the recycling chain view by unpacking multi-level information processing needs at the firm, supply chain, and industry levels, and by critically evaluating the four BCT-enabled information processing capabilities. Second, we extend OIPT by identifying three information processing fit mechanisms (Bensaou and Venkatraman, 1995; Busse *et al.*, 2017)—functional, contextual, and systemic fit—and employ them to enable a more critical assessment of BCT applications. Third, we move beyond the generic and conceptual discourses on BCT's disruptive potential to recycling chains (Saberi *et al.*, 2019; Xie *et al.*, 2023) by analysing real-world cases that reveal how BCT is embedded in recycling chains.

The structure of this paper is as follows: Section 2 provides the theoretical underpinning of recycling chain and BCT applications along with the OIPT perspective. Section 3 introduces the research method applied in the study. Section 4 illustrates detailed BCT applications for each case, and cross-case analysis. Section 5 critically discusses BCT-enabled information processing in recycling chains. Finally, Section 6 summarizes the research, discussing the research and managerial implications, limitations, and future research directions.

2. Theoretical background

2.1 Recycling chain and technological enablers

The circular economy shifts us from the traditional 'take–make–use–destroy' linear model towards restorative and regenerative models (Zhang *et al.*, 2021). A foundation concept is the 'closed-loop supply chain', wherein end-of-life products and packaging are returned to producers for recovery and reuse—essentially, reverse logistics focused on efficient collection, sorting, and reprocessing (Pagell *et al.*, 2007). Closely related is the waste reverse supply chain, defined as '*a strategic network involving all actors engaged in the post-consumption flow of discarded products, encompassing processes such as collection, transportation, recovery, and disposal with the aim to recapture value or ensure proper disposal*' (Van Engeland *et al.*, 2020, p.2). A more ambitious extension is the 'circular supply chain' (de Lima *et al.*, 2024; Zhang *et al.*, 2021), which adds aspirational goals of zero waste and prolonged material life by minimizing resource extraction and maximizing reuse and remanufacturing across industrial and natural ecosystem.

Despite their conceptual differences, these concepts emphasize the need to account for multi-tier structures and to coordinate multiple actors, particularly when assessing the sustainability of lower-level suppliers (Tachizawa and Wong, 2014; Wilhelm *et al.*, 2016), which, in turn, entails complex information processing needs (Hamann-Lohmer *et al.*, 2023). Specifically, focal companies may lack information about lower-level suppliers or may have insufficient influence on them (Tachizawa and Wong, 2014). In addition, tracking waste material may be intrinsically difficult, particularly when waste is sorted and shredded into smaller fractions (Xie *et al.*, 2023). Focal companies normally lack control over the entire recycling chain, and this lack of information makes it difficult to establish a complete chain of custody (Gong and Xie, 2023).

Technology plays a pivotal role in enhancing information processing across recycling chain-related patterns as Table I summarizes. We categorize four enabler types: sensing and identification; connection, storage, and communication; production; and data analytics. In practice, these technologies often operate in concert: BCT, for example, provides a trusted data-assurance layer across sensing, communication, and analytics processes (Centobelli *et al.*, 2022), and its integration with the Internet of Things (IoT) further strengthens identification capabilities and end-to-end traceability (Saberi *et al.*, 2019).

---Table I about here---

2.2 Blockchain application in supply chain management

Blockchain technology is increasingly recognized as a transformative force in supply chain management by enhancing information processing (Martinez *et al.*, 2019; Tuladhar *et al.*, 2024). Among its most widely adopted applications is traceability, enabling firms to access real-time, reliable data (Brusset *et al.*, 2024; Hald and Kinra, 2019). Through a tamper-proof ledger structure, BCT creates end-to-end verifiable data trails that support tracking of products (Tuladhar *et al.*, 2024). This feature holds significant promise, particularly in combating counterfeiting (Shen *et al.*, 2022), which is especially critical in high-value sectors such as luxury goods (Klöckner *et al.*, 2023). By enabling trustworthy records, BCT shapes trust mechanisms by allowing consumers, regulators, and companies to establish cross-organizational trust (Brookbanks and Parry, 2022; Yavaprabhas *et al.*, 2022).

In addition, BCT has the potential in process automation and cross-organization collaboration (Lumineau *et al.*, 2021). By leveraging smart contracts, BCT facilitates the automated execution of predefined conditions (Martinez *et al.*, 2019), and potentially eliminates the need for intermediaries (Gregory *et al.*, 2024). Furthermore, BCT functions as a decentralized infrastructure for information sharing (Lumineau *et al.*, 2021), enabling coordination across organizations while protecting sensitive data (Chaudhuri *et al.*, 2024; Hald and Kinra, 2019).

These BCT features have proposing potentials in sustainable supply chains, see Online Supplement (Section 1), such as ethical sourcing, environmental responsibility, and social accountability (Marques *et al.*, 2025; Saberi *et al.*, 2019). However, most studies position BCT primarily as a technical tool (Bhatia and Gangwani, 2025), offering limited systematic insight into how it operates as part of broader information processing mechanisms. Although BCT is often assumed to enhance information processing efficiency in response to uncertainties (Tuladhar *et al.*, 2024), such a static view of matching overlooks the multi-level nature of recycling chains, which may require additional mechanisms. Moreover, prior research has noted that many technological assumptions about BCT diverge from its real-world implementation (Lustenberger and Spychiger, 2025). This suggests that BCT's capabilities may not always align with actual information processing needs and, instead, calls for a more systemic exploration of what truly constitutes BCT-enabled information processing capabilities and the underlying mechanisms through which they operate.

2.3 The potential of blockchain for recycling chains

Following the general expositions of BCT in supply chain, we draw out key features that are especially pertinent to its application in recycling chains. We begin by describing the type of BCT ('permissionless') that has attracted the most excitement in recent public discourse (Lumineau *et al.*, 2021).

First, BCT enables the progressive addition of immutable records as items move through the supply chain (Gregory *et al.*, 2024). This entails a computational technique called 'hashing' which produces a compact signature of a larger dataset; each time the dataset is amended, the hash becomes part of the revised record (Saberi *et al.*, 2019). In recycling, this ensures that, once data are recorded on-chain, they remain authentic and immutable, thereby supporting claims of material authenticity (Centobelli *et al.*, 2022). The second feature is BCT's principle of accessible and transparent data. Instead of being controlled by a single entity, data are stored in a shared, distributed structure (Lumineau *et al.*, 2021). This enables more open, democratic access to information (Danese *et al.*, 2021), which is particularly valuable for managing the multi-tier complexity of recycling chains. The other element is 'smart contracts', which enable automated execution of predefined agreements across organizations. By embedding BCT into business logic, they ensure data reliability and allow business processes that traditionally required human oversight to be automated (Gregory *et al.*, 2024).

Some studies have explored how these features support recycling objectives; for example, in enabling compliance with recycled product manufacturing processes, recycling regulations, and waste management information (Baralla *et al.*, 2023; Bhatia and Gangwani, 2025). For instance, BCT can help manufacturers to meet policy requirements for packaging disclosure and demonstrate the use of recycled materials through digital product passports (Chaudhuri *et al.*, 2025). In waste collection, tokenization can incentivize participation from informal waste collectors (Gong *et al.*, 2022) and integration capabilities appear well-suited to enabling multi-party collaboration (Xie *et al.*, 2023).

Nevertheless, barriers to adoption remain evident (Baralla *et al.*, 2023), and we still lack a systematic understanding of how BCT is embedded in recycling chains to meet multi-level information processing needs. It also remains unclear how BCT's potential can be realized and through which mechanisms, underscoring the need to analyse concrete use cases and further investigate how BCT functions in recycling chain settings to enhance information processing.

2.4 Organizational information processing view

Building on the work by Galbraith (1974), information processing can be framed as the *process of gathering, interpreting and synthesis information in organizational decision making* (Tushman and Nadler, 1978, p.614). The core premise is that the higher the level of task uncertainty or challenge, the greater the amount of information processing required to achieve task performance. Organizations can either increase their information processing capabilities, (e.g., the deployment of information systems) or reduce the information processing needs (e.g., the creation of slack resources) (Galbraith, 1974; Hamann-Lohmer *et al.*, 2023).

Extending this lens to the supply chain level, Busse *et al.* (2017) identified three categories of 'sustainability-related uncertainties': task, source, and supply network uncertainties. Task uncertainty arises from product-related characteristics, source uncertainty from supplier differences, and supply network uncertainty from the structural complexity of the supply chain, encompassing horizontal, vertical, and spatial dimensions. In the recycling chain which involves the multi-tier structure, focal companies are encouraged to extend oversight supervision to improve visibility and control (Wilhelm *et al.*, 2016). However, the sustainable practices of upstream suppliers often remain opaque and outside the scope of supervision (Tachizawa and Wong, 2014), highlighting the need for information processing.

Blockchain technology offers proposing capabilities to support information processing, such as increasing data authenticity for reducing fraud (Tuladhar *et al.*, 2024), and facilitating process efficiency (Martinez *et al.*, 2019). These capabilities should be directed toward achieving "information processing fit" that can mitigate information asymmetries (Aben *et al.*, 2021), enhance analytical capabilities (Srinivasan and Swink, 2018) and support supplier sustainability performance (Busse *et al.*, 2017). Task–technology fit may help to examine the fit, which describes the degree to which a technology's functionalities correspond to the tasks performed by its users. As Chaudhuri *et al.* (2024) suggested, the BCT application is not merely a technical issue; it also requires close alignment between technological capabilities and users' task demands.

To facilitate information processing in recycling chains, increasing the *reliability* of data might be more significant than increasing the *amount* of data. However, what remains unknown is how BCT-based information processing capabilities can interact and be aligned with the information processing needs of recycling chains, such as regulating upstream suppliers, verifying the use of recycled materials, and demonstrating product lifecycles in response to policy requirements, so that these capabilities are neither overloaded nor underutilized (Flynn *et al.*, 2016; Srinivasan and Swink, 2018). However, there is limited understanding of how information processing fit is achieved and dynamically adapted over time (Bensaou and Venkatraman, 1995), particularly as both technologies and operating environments continue to evolve (Lorentz *et al.*, 2020).

3 Methods

This research adopts an exploratory case study approach due to its methodological fit (Siggelkow, 2007). First, this approach fits the motivation for answering the 'how' related research questions (Voss *et al.*, 2002), aligning with our aim to understand how BCT is embedded within recycling chains to address information processing needs. Second, case studies are well-suited to generating novel, contextually grounded insights into underexplored phenomena, such as the complex nature of BCT implementation in recycling chains. Given the emergent and evolving nature of BCT adoptions, this approach enables us to go beyond technical conceptualization and observe actual practices that are not yet fully theorized in the existing literature. Third, it supports our use of theoretical elaboration (Fisher and Aguinis, 2017), where we refine and extend existing theory (i.e., OIPT) to conceptualize and execute the empirical setting of BCT applications in recycling chains through a contextualized logic (Ketokivi and Choi, 2014). This approach emphasizes abduction reasoning (Dubois and Gadde, 2002), where we iterated the OIPT literature and our empirical data to uncover the underlying information processing mechanisms through which BCT is embedded in recycling chains. Figure 1 specifies the research process.

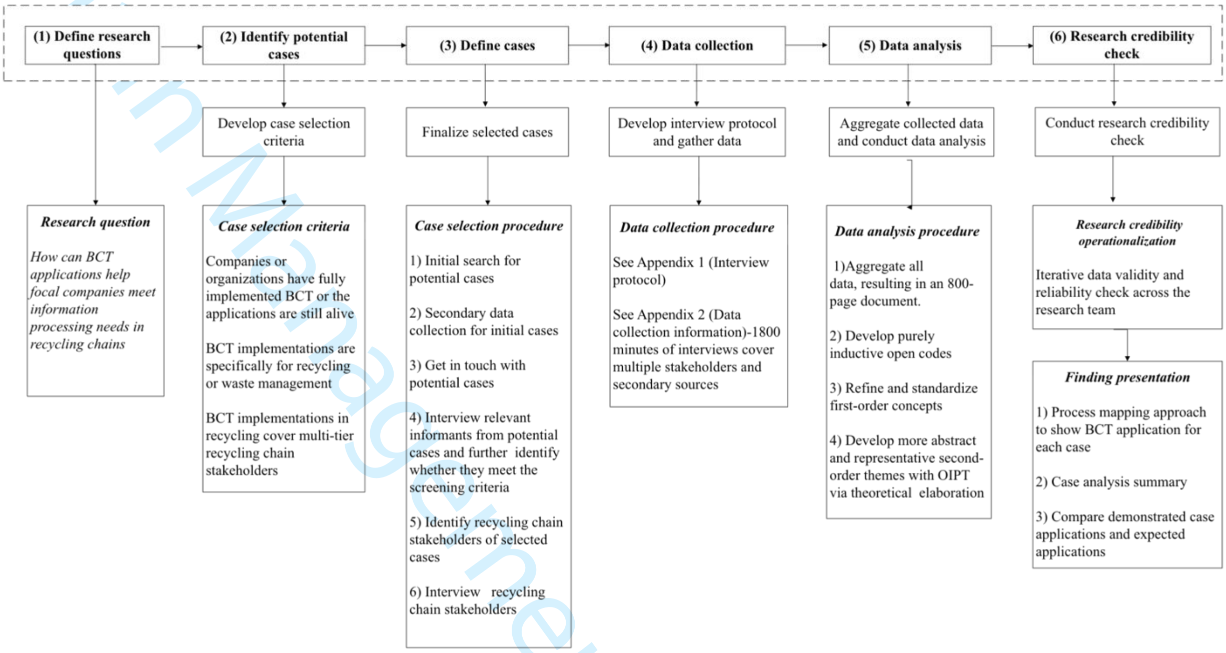

Figure 1 Research process

3.1 Case selection

We applied a purposeful sampling approach to select the best practices that have implemented BCT in their recycling chains (Patton, 2002). This approach is well suited for exploratory research, as it enables the selection of cases that are both information-rich and representative (Klöckner *et al.*, 2023; Marques *et al.*, 2025). We aimed to capture the diversity across recycling contexts, deepen insight into underlying mechanisms and boundary conditions, and enhance both theoretical richness and generalizability (Ketokivi and Choi, 2014). Accordingly, it allowed us to select exemplar cases with different information processing mechanisms, recycling chain structures, and BCT applications, thereby revealing divergent patterns.

Following Voss *et al.* (2002), we set case boundaries that directly addressed our research question. First, cases in the conceptual stage that lacked real BCT implementations were excluded. For example, some of the cases had just launched BCT initiatives, and their BCT-based information processing may be overly generic and inadequate for real recycling practices. Second, we controlled for industry-level diversity by focusing our sample on multi-tier recycling contexts, as BCT functionality can vary significantly across sectors (Hastig and Sodhi, 2020). We also took into account that specific institutional factors may influence BCT adoption decisions (Saberi *et al.*, 2019), but we did not limit our case selection to a single geographic or political region; rather, we purposefully selected cases from diverse global contexts. Due to the scarcity of mature BCT implementations in practice (Xie *et al.*, 2023), this approach helped us to reduce restrictions imposed by specific industries and institutional contexts and enhance the generalizability. Third, due to the technical characteristics of BCT, we excluded cases where the application could not be extended to other supply chain stakeholders, which is usually considered as an internal information system without decentralization or integration qualities (Gregory *et al.*, 2024). Accordingly, two key selection criteria were the case's ability to involve multiple stakeholders and provide access to observable data interactions.

Using a scoping review and supplemented by publicly available data, we initially identified over 10 potential cases worldwide via Google. After analysing secondary sources, we excluded cases that were either in the rudimentary stages of implementation or not specifically related to recycling. Subsequently, we developed refined research protocols to clearly define the study's objectives, sent invitations to participate, and received confirmations from five companies. To ensure that the selected cases aligned with our criteria, we conducted pilot interviews to further evaluate their suitability; this resulted in another two being dropped. Following the procedure outlined, three cases were selected.

Alpha is a Dutch textile company specializing in recycled fabrics, with core operations in China and India, and its products are mainly sold to the European market. Its recycled fabrics are primarily used in products such as home appliances, finished garments, shopping bags, and furniture, and are made from recycled plastic materials, mainly derived from wasted polyethylene terephthalate (PET) bottles. To enhance transparency, Alpha has implemented BCT to trace the use of PET bottles throughout the production process and to demonstrate the full product life cycle to clients.

Beta is a multinational British fast fashion retailer that has publicly committed to using 100% recycled, repurposed, or sustainably sourced materials by 2030 as part of its sustainability strategy. However, following public scrutiny and a suspected greenwashing controversy, Beta has faced pressure to substantiate its environmental claims. Specifically, acknowledging that end-consumers are increasingly sceptical of brand-led corporate social responsibility messaging, Beta has turned to BCT to trace the reuse of clothing trimmings and to demonstrate the production journey of mixed recycled garments directly to end consumers.

Gamma is a social enterprise operating in Indonesia, where it leverages BCT to document ocean plastics collection activities. Declining marine environmental conditions have severely impacted local fisheries, contributing to rising unemployment. In response, Gamma launched a community-based initiative that incentivized local fishermen to engage in paid plastic collection. Its business model revolves around selling “plastic credits”, the certified proof that a specific quantity of marine plastic waste has been collected. Like a crowdfunding approach, Gamma designates collection zones and raises funds from the public to support the effort. To justify the premium price of its credits, Gamma relies on BCT to provide highly credible, verifiable, and transparent documentation of the collection processes.

3.2 Data collection

Data were collected between November 2021 and January 2024. The primary data source was interviews and, depending on each case, we took the widest range of stakeholders across the multi-tier recycling chain that we could, including the focal company, BCT technology providers, validation companies, multi-tier suppliers, and external experts. We purposefully reached out to key informants who were major players in the planning and specific deployment of BCT, e.g., sustainability managers, project managers, and CEOs of small suppliers. These multi-informant roles were instrumental in helping us to reduce single interviewee and researcher bias.

In addition, we customized the interview protocols (Online Supplement, Section 2) for different stakeholders to obtain comprehensive details of BCT implementation. It is important to note that, although the interview questions varied according to role, we maintained a uniform unit of analysis—i.e., the BCT project, configured by the focal companies and their multi-tier recycling chain stakeholders. Overall, we conducted 30 interviews (average 60 minutes for each) for the three BCT use cases, and all interviews were recorded with permission. Additionally, one focus group with Beta and one workshop with Gamma were conducted. These sessions comprised product demonstrations, project presentations, industry overviews, and discussions of future scale-up plans. These interactions enabled us to validate informants’ views, probe ambiguous responses, and identify additional interviews.

We also conducted site visits and observations, including visits to recycling factories and textile mills, and obtaining product samples. In addition, we collected archival data from the case companies, including internal sustainability reports, annual reports, technical documents, and media coverage. Importantly, we were granted access to proprietary information related to BCT deployment and specific project work plans. For example, we had access to the BCT system to view the demo version, which helped us to understand the data entry and visualization processes. These multiple data sources supported triangulation and enhanced the validity of our findings. Table II shows the data collection details.

---Table II about here---

3.3 Data analysis

This research followed a rigorous qualitative coding procedure recommended by Gioia *et al.* (2013), using an abduction approach to elaborate on the theories (Fisher and Aguinis, 2017). We started with a verbatim transcription of all documents and manual checks to familiarize ourselves with the data. In total, the approximately 1800 minutes of interviews and secondary sources resulted in 800 pages of text, and all collated documents are organized into NVivo-14 software for subsequent analysis. Online Supplement (Section 3) shows the detailed coding structure and examples.

In the first step, we conducted open coding for each document/transcript to capture interviewees' perspectives and inductively generate open codes (Strauss and Corbin, 1990). This process allowed for detailed within-case analysis of BCT applications (Eisenhardt, 1989). We also applied a process mapping approach (New, 2004) to visualize each recycling chain's structure and identify how BCT configurations were embedded across data flows, covering content, blockchain scope, input/output mechanisms, and visibility settings (see Online Supplement, Section 4). Similar or duplicate codes were systematically aggregated into more concrete 'First-order' concepts, following Gioia *et al.* (2013). For example, we aggregated '*brand image and marketing needs*' and '*transparent and unbiased demonstration of sustainable practices*' into 'Firm-level uncertainty' of information processing needs. Across cases, we also identified distinct types of uncertainty and how specific BCT configurations were used in response, and recurring pattern variations began to emerge. For example, BCT traceability patterns varied, some required capturing the full lifecycle of materials, while others focused exclusively on the waste collection phase. These differences shaped the granularity and completeness of data records, which we categorized as dimensions of transparency breadth and depth.

Second, we progressively refined the first-order concepts into more abstract and representative second-order themes via a theoretical elaboration approach with OIPT (Fisher and Aguinis, 2017). For instance, we identified a range set of information processing needs, which were framed at the firm, supply chain, and industry levels. Additionally, we observed multiple patterns of four enhanced information processing capabilities. Using this pattern-matching approach (Eisenhardt, 1989), we visualized the aggregated themes to enable effective case comparisons. Next, these second-order concepts were then abductively connected to the constructs of OIPT (Busse *et al.*, 2017). Following OIPT's premise that higher levels of uncertainty increase information processing needs (Galbraith, 1974), we conceptualized the multi-level information processing needs of recycling chains. Then we aligned them with corresponding BCT functionalities under the category of "BCT-enabled information processing capabilities".

To facilitate independent coding, we created shareable, encrypted folders containing all transcribed documents and data sources from the three cases. To ensure validity and reliability, the first author conducted three rounds of coding on the collated documents, iteratively refining existing constructs and incorporating newly emerging ones. To strengthen inter-coder reliability, the coding process was discussed and validated with the other two coding authors. Furthermore, a fourth author, independent of the coding process, critically reviewed the theoretical constructs to challenge assumptions and mitigate potential bias. Following Gibbert *et al.* (2008), Online Supplement (Section 5) summarizes the credibility test.

4. Results

This section presents the case analysis results for the three cases (Alpha, Beta, and Gamma). Section 4.1 analyses the BCT application for each case. We also examine each company's BCT application and multi-tier recycling chain using process mapping (New, 2004). This approach visualizes the original recycling process, need for BCT, recorded information, data management, and validation (see Online Supplement Section 4). Section 4.2 draws comparisons with the information processing needs and BCT-enabled information processing capabilities across the three cases.

4.1 BCT application in each case

4.1.1 Alpha

Information processing needs of Alpha's recycling chain: Alpha's orders are driven by downstream customers, and, upon receipt of an order, the key tasks are to ensure that there is an adequate supply of good quality goods (e.g., waste bottles) and that the order batch can be delivered on time. The key challenge in conducting effective monitoring is visibility. Traditional approaches relied on cumbersome and costly manual inspections and sample testing. Moreover, each supplier's internal systems are independent, and linking systems between companies is difficult due to concerns about the protection of sensitive information (such as prices). As explained by a Tier 2 supplier: "*There's no connected system between companies, I don't want my customers to know where I source my materials or how much I'm paying for them*" [A5]. Furthermore, the textile industry is known to be rife with fraud. Normally, certificates are obtained by sample verification and factory visits, but these mechanisms are widely perceived to be unreliable. As a result, manufacturers can easily make misleading claims. Overall, the industry suffers from uncertainties around counterfeit products, vicious competition, and a lack of regulation.

BCT-enabled information processing capabilities in Alpha: The recycling chain starts with waste pickers collecting colourless PET bottles. The pickers then resell the collected waste to waste collection centres, where it is sorted and compressed into standard bale blocks. The recycling company then cuts, washes, and shreds the bale blocks to produce pellets or flakes out of the waste plastics. These plastic products are then transported to fabric mills to be woven, in a similar way to traditional plastic spinning processes. After dying and trimming, the finished product is ready for export to business-to-business (B2B) customers.

To provide proof of using recycled materials, Alpha operates two parallel systems: a BCT-enabled system for tracking products and a chemical testing method for physical testing. The essential aim is to demonstrate that products were made from recycled material, which meets clients' sustainability requirements. Given the dispersed nature of collection areas and cost constraints, tracing occurs at the bale level rather than per bottle. Each bale is sealed with a tamper-evident wrapper and labelled with a QR code. At every handoff, the receiving party scans the code to confirm the batch number before unpacking. Each tier in the chain also uploads time-stamped photos and videos to a blockchain-based app, ensuring that all parties process the correct batch. After reprocessing, suppliers reseal the material, repeat the scanning and uploading steps, and pass it on, culminating in finished textiles co-branded with Alpha. These textiles carry QR codes through which end consumers can retrieve the full production history.

End consumer access is customized—e.g., how many waste PET bottles the product is made from—without seeing proprietary supplier details. Compared to conventional record-keeping, BCT significantly enhances credibility and process visualization. By enabling data validation and circulation across suppliers, BCT enriches information granularity and data authenticity in conjunction with supporting certifications. This reduces the reliance on costly manual inspections.

4.1.2 Case Beta

Information processing needs of Beta's recycling chain: Although Beta is committed to sustainability, a major challenge in Beta's multi-tier structure is information fragmentation. Beta lacks direct visibility into its upstream processes and relies on Tier-1 suppliers to relay sustainability data, a process prone to gaps and delays. When Tier-1 suppliers have higher bargaining power, they can exert significant leverage in negotiations and order management. This information asymmetry complicates the integration of cross multi-tier recycling chains. Traditionally, Beta uses transaction certificates issued by third-party certifiers to track batches between organizations. However, this requires cumbersome manual handling—documents are exchanged repeatedly and data entry is laborious. As one verification partner noted: "*The transaction certificates process is heavy with a lot of manual work. You've got documents being shipped back and forth, people constantly filling things out and sending them again*" [B8].

BCT-enabled information processing capabilities in Beta: Beta developed a BCT-enabled tool to transparently show the full lifecycle of a premium sustainable shirt collection, highlighting its use of cutting waste. Beta's recycling begins when a waste collection company (Tier-3) collects cutting waste (leftover wool material generated during garment production). These wool trimmings are sent to a fabric manufacturer (Tier-2), where the trimmings are blended with other materials and reprocessed into yarn. The yarn is subsequently inspected, made into garments by a manufacturer (Tier-1), and delivered to Beta's warehouse before reaching retail channels.

Beta hoped to be able to tell an authentic product story so that consumers could see more granular information rather than just relying on brand claims. Each garment carries a QR code or embedded chip that directs consumers to a detailed product page, which traces the origin of raw materials, waste-collection methods, production steps, and logistics data. This approach is different from traditional practices, where customers must accept generalized brand claims but cannot independently verify material authenticity. To ensure data integrity, Beta partnered with a reputable verification firm to design a system that balances comprehensive traceability with streamlined presentation, avoiding the impracticality of exposing every minor production detail while still offering meaningful, granular insights.

4.1.3 Case Gamma

Information processing needs of Gamma's recycling chain: Given the premium positioning of Gamma's waste-collection services, data must be both transparent and comprehensive, documenting every stage of the retrieval process. To uphold its brand and lend credibility to its "plastic credits," Gamma's documentation and verification protocols must withstand rigorous, independent scrutiny rather than rely solely on internal attestations.

However, the decentralized, multi–checkpoint nature of ocean-plastic recycling presents an information-processing challenge. Plastics pass through numerous handoffs—collection at sea, offshore storage, coastal transport, and delivery to sorting centres—so that any gap in the chain of custody undermines the integrity of the entire record. Ensuring robust oversight therefore requires seamless linkage across all collection activities and interfaces—a level of continuity that photos or videos alone cannot guarantee. Compounding this challenge is the lack of a standardized definition for "ocean plastics." As one informant (G3) explained, "*Some certification schemes count any plastic collected within 50 km of the coastline as marine waste, whereas stricter standards recognize only plastic recovered directly from marine waters*."

BCT-enabled information processing capabilities in Gamma: Waste collection begins with the identification and designation of a marine zone for debris collection, after which pairs of fishermen are deployed to gather marine waste. The collected waste plastics are baled and stored offshore storage, where Gamma staff weigh and log each bale before secondary transport to a sorting centre for a second weighing and preliminary separation. A third-party auditor conducts weekly unannounced sampling inspections to verify data integrity. Time- and weight-stamped records feed into analytics models that optimize collection routes and visualize performance under varying conditions. The sorted plastics are then compressed into bales and transported to local waste centres or disposal partners. From there, the plastics can follow one of three routes: remanufacturing into plastic pellets, converting waste to energy, or incineration for substandard material.

To capture this journey in both physical and virtual forms, Gamma implements a BCT-based SaaS platform. Each fisherman logs into a digital account, triggering a GPS-verified check-in at the designated collection site. Data from multiple checkpoints—collection, offshore storage, sorting, and audits—are uploaded via API to the BCT-based platform. Any batch exhibiting data inconsistencies or irreconcilable records is immediately voided and excluded from "plastic credit" issuance. Gamma also developed business intelligence systems such as PowerBi software for data visualizations, to enhance process efficiency, e.g., by comparing the effectiveness of collection in different types of weather and in different areas. This solution is also complemented by a robust online and offline verification model.

Overall, Gamma has redefined a solution to address the lack of consensus on what constitutes ocean plastics by providing an end-to-end, transparent record of every collection activity. As the BCT manager observed: "*Especially after COVID hit, I wasn't able to travel to Indonesia. But working with the blockchain system and the application still allowed us to maintain the control points we needed and to get back before I go further down that line"* [G2].

4.2 Case analysis summary

This section provides cross-case analyses via a tabular approach (Eisenhardt, 1989). First, we listed the findings of specific recycling chain information processing needs. Second, we mapped out the BCT-enabled information processing capabilities demonstrated by the cases.

4.2.1 Recycling information processing needs

Based on the iterative coding, we found some degree of similarity in recycling chain information processing needs on three levels. For example, although they were in different industries, they suffered similar supply chain coordination difficulties.

Firm-level uncertainty: Focal companies are under growing pressure to maintain their brand image and meet marketing expectations, especially brands that are subject to external scrutiny and eager to avoid accusations of greenwashing. This means that they must transparently demonstrate their sustainability practices: *"Sustainability is now central to these fast-fashion giants. When they engage us for product delivery, it's no longer just about quality or performance; they demand detailed sustainability data"* [A2].

Supply chain-level uncertainty: The cases reveal significant information processing needs in achieving integration across recycling chains. Integration extends beyond inter-organizational linkages across different supplier tiers and requires seamless end-to-end access to, consolidation of, and communication of data. However, many focal companies often have little to no knowledge of who their indirect suppliers are, making it even more difficult to manage complex, cross-tier data flows: "*Most data reside in our suppliers' own systems. Brands often have no—or very limited—access, and information typically only passes between adjacent tiers"* [B4].

Industry-level uncertainty: Wider industry conditions introduce further ambiguity. In recycling contexts in particular, the lack of unified standards leaves open questions; for example, what proportion of recycled content qualifies a material as genuinely 'recycled.' A common challenge involves verifying the origin of recycled materials, as the proliferation of overlapping or inconsistent standards has led to widespread confusion. Many recyclers exploit the voids in certification schemes to overstate their claims, which command higher prices. This vicious cycle fuels industrial trust issues and immoral practices.

4.2.2 Blockchain-enabled information processing capabilities in recycling chains

Despite variations in how BCT solutions meet information processing needs across recycling chains, these cases exhibit four BCT-enabled information processing capabilities.

Transparency: The three cases apply different BCT configurations, all of which aim to present data transparently via a digitized approach. This digitalization requirement demands not only real-time data recording, but seamless data sharing across all recycling chain tiers. The drivers for transparency, however, vary by context: Alpha visualizes transparent recycled textile production to B2B customers; Beta focuses on production and sells sustainable products to B2C customers; Gamma documents the full waste collection process to sell waste credits because clients buy these credits to support sustainability compliance.

The cases illustrate two dimensions of transparency within the recycling chain. *'Breadth'* transparency refers to the scope of cross-tier traceability—for example, the ability to present end-to-end lifecycle evidence and a complete chain of custody. *'Depth'* transparency reflects the granularity of information captured and disclosed. The level of granularity varies depending on the contextual conditions of each case. A common approach is scanning the uniform packaging, such as bales, rather than tracking each individual product, due to cost and feasibility considerations. As explained by the G5's verification company: "*We can look at information from a mass balance perspective, whether the input and output make sense, it's more about checking the supporting documents and whether the logic behind them holds up*" [G5]. Moreover, each case provides customizable visibility. For example, Beta grants its auditor full data access while restricting sub-suppliers to data entry only, illustrating how firms tailor transparency to stakeholder needs.

Immutability: Immutability safeguards information authenticity and integrity. The cases show fruitful data-feeding methods, a similar approach being that all information is decentralized data entry with validation rather than being controlled by one party alone. BCT's hashing mechanism underpins this immutability, while every action generates a new encrypted hash, producing a unique transaction record that can be traced back to specific batches. Other complementary mechanisms, such as digital signatures, audit-support tools, and mutual authentication are also applied in cases for data integrity.

To address the "garbage in, garbage out" problem, each case implements encrypted data assurance and verification protocols. Alpha requires mutual recycling chain members to upload their data, following the mass balance approach. In other words, suppliers can verify their own information and feed in information after confirmation. Beta and Gamma, on the other hand, engage third-party auditors to apply professional validation metrics and ensure data authenticity. To improve the objectivity and efficiency of data feeding, other smart devices are used in cases to reduce manual error, such as QR codes, smart weighing devices, and sensors.

Integration: BCT's decentralized ledger and associated data-synergy solutions enable seamless integration across recycling chains. By digitizing material flows and complementing traditional compliance approaches, this integration of diverse data sources—from multiple actors within the recycling chain—supports more effective governance practices across recycling chains. Each case adopts a tailored engagement strategy: Alpha offers a simple upload interface that imposes minimal extra burdens to suppliers; Beta leverages brand influence to engage suppliers; Gamma incentivizes fishermen with weight-based payment.

Additionally, there are differences in how integration with BCT is formulated: Alpha's recycling chain is more centralized, involving suppliers' supervision and data capture, which is then consolidated into a database for customers. As illustrated by Alpha's blockchain manager: "*While data confirmation and verification are carried out independently by external parties, they operate within our framework. This setup is necessary because, if data were allowed to flow freely from suppliers or other actors, we wouldn't be able to control what's coming in"* [A2]. By contrast, Beta and Gamma aim to enhance data synergy among multiple parties with a decentralized feature, notably involving third-party verification in monitoring and providing business intelligence for further analysis.

Trust: All cases highlight how BCT functions as a trustworthy tool for supporting brand image and the disclosure of verifiable data. Rather than relying solely on internal sustainability claims, public oversight and traceable chains of custody help to extend brand accountability externally. This trust mechanism facilitates inter-organizational collaboration: *"Trust between suppliers has improved, at least they now know the goods they receive are authentic and verifiable. That's why suppliers are signing new contracts with us [BCT provider]"* [B3].

However, none of the cases demonstrates a fully "trust-free" model (Yavaprabhas *et al.*, 2022). Instead, BCT is shown to supplement traditional trust systems, and the entirely algorithmic or smart contract-based governance has not been formed. For example, Alpha does not apply BCT to replace original global recycling standard certificates but uses blockchain to add an extra layer of credibility. In the multi-tier structure context, suppliers still rely on prior relationships, while BCT's immutability shifts the locus of trust to the technology itself. The benefits are evident: Alpha indirectly guides suppliers on compliance; Beta fosters sustainable trust in fast fashion brands and Gamma has increased its plastic credits scope, gradually expanding its collection activities in other regions.

Online Supplement (Section 6 and 7) provides further representative quotes across the cases.

5. Discussion

In this section, we draw three key points from the analysis of our cases, which provide lessons about the nature of information processing in recycling chains, the nature of BCT's contribution to the domain, and the information processing fit between these two dimensions.

5.1 The nature of information in recycling chains

The OIPT posits that performance hinges on aligning the information processing fit (Bensaou and Venkatraman, 1995; Galbraith, 1974). Our case studies point to the inherent complexity and dynamics of recycling chains and the limited scope for actions that seek to lower information processing needs, for example, by standardization. The detailed nuances of each case suggest that recycling chains reflect more diversity than often assumed, making generic, domain-spanning structures and business processes of limited use (Denizel and Schumm, 2023).

An important and helpful way to frame this discussion is in terms of multi-level uncertainty at firm, supply chain, and industry levels. It is interesting to note that our cases do not fit neatly with Flynn *et al.* (2016) taxonomy, where micro uncertainty concerns quantifiable technical inputs, meso uncertainty relates to inter-firm behaviours, and macro uncertainty relates to the external environment. We identify a type of low-level information uncertainty that relates to a richer perspective than just counting products or forecasting sales. Recycling introduces a set of uncertainties about how products are classified and how such information can be trusted. For example, the lower level of uncertainty relates less to how many products need to be in a warehouse and more to whether items can be genuinely classified as recycled, together with ambiguity about which criteria and knowledge may be applied to that specific situation. This information asymmetry amplifies regulatory demands for sustainable practices, while brands face increasing pressure to substantiate and disclose their sustainability claims.

Similar to the “sustainability-related uncertainty” proposed by Busse *et al.* (2017), we enrich ‘supply chain-level uncertainty’ by accentuating the fragmented, multi-tier configurations of recycling chains for information processing. The cases underscored that a lack of sub-supplier information results in coordination failure and ambiguous chains of custody. Focal companies are encouraged to integrate multi-tier stakeholders. For example, the cases demonstrated a downward orientation towards realigning customers’ sustainable preferences (*Alpha, Gamma*), and an upward orientation towards connecting upstream suppliers (*Beta*).

In addition, uncertainty at the industry level is compounded by the lack of consistent standards for determining what constitutes recycling, resulting in broad ambiguity and diminished trust (Denizel and Schumm, 2023). This consistency is logical because there is no uniformity in the mode of circularity of products, by-products, and waste outputs (Pagell *et al.*, 2007). This is especially pronounced for low-value materials such as plastics and textile waste, where small suppliers rarely comply proactively (Xie *et al.*, 2023). The market-driven orientation of this recycling patterns depends on the price of virgin materials, while some collection activities are contributed by informal sectors (Gong *et al.*, 2022). However, focal companies usually engage in recycling under coercive or normative pressures, relying on sustainability reports and third-party certificates.

In general, recycling chains demand context-intensive, rather than one-size-fits-all, technological solutions, and these intertwined uncertainties are intensified by recycling chains' complex and fragmented nature (Xie *et al.*, 2023). This research extends Busse *et al.* (2017) framework of sustainability-related uncertainty by specifying the uncertainties associated with recycling chains, in particular, at firm, supply chain, and industry levels. It also broadens OIPT's scope from the intra-organizational processing (Galbraith, 1974), to the nuanced information needs of multi-tier recycling chain setting. Thus, we propose:

> *Proposition 1*: In recycling chains, higher uncertainty at the firm level (information asymmetries and sustainability pressures), the supply chain level (chain of custody and coordination needs), and the industry level (standardization and trust issues) increases information processing needs across the three levels.

5.2 Critical view of the nature of BCT-enabled information processing

Our study points to the fact that BCT may be an important approach in addressing these information processing needs by enhancing information processing capabilities in transparency, handling of immutability, integration, and trust-adding.

Consistent with the existing literature, traceability remains the predominant way in which BCT empowers information processing (Martinez *et al.*, 2019; Tuladhar *et al.*, 2024). However, in multi-tier recycling chains, focal companies need to unpack traceability into both breadth (linking all tiers end-to-end), and depth (capturing granular data at the batch, production, and logistics levels), that beyond generic features like visualization. Moreover, while prior research treats immutability primarily as a proposing feature for security (Centobelli *et al.*, 2022), we show a practical pattern for securing immutability. This can be driven by commercial constraints: selective data feeds, access permissions (Danese *et al.*, 2021), and cost optimization (Klöckner *et al.*, 2023), and other complementary tools are effective, such as digital signatures, audit tools, and mutual authentication. We demonstrate that BCT-enabled transparency and immutability serve not only as tools for batch tracking and data authenticity assurance (Baralla *et al.*, 2023) but also as strategic instruments for focal companies to showcase their brand image and market their sustainable practices. In doing so, they can potentially address firm-level information processing needs.

Echoing prior research, we find that BCT facilitates the integration of multi-tier stakeholders (Gong *et al.*, 2022), potentially mitigating coordination and data fragmentation uncertainties at the supply chain level. We extend this view by showing that such integration is driven not only by technological linkages but also by stakeholders' willingness to share data, which, in turn, requires additional coordination (Xie *et al.*, 2023). These dynamics materialize through digital interfaces, account systems, and identity management schemes that bridge physical and digital identities (Klöckner *et al.*, 2023). Importantly, integration goes beyond mere connectivity to constitute a socio-technical synergy (Chaudhuri *et al.*, 2024), shaped by contextual factors such as data standardization, access control, and role coordination.

Furthermore, we confirmed that BCT can serve as a valuable tool for strengthening inter-organizational trust (Brookbanks and Parry, 2022), helping to address industrial information processing needs arising from non-standardization and trust issues. However, the much-anticipated fully "trust-less" model—where smart contracts alone enforce agreements without the need for trust development—has yet to materialize (Yavaprabhas *et al.*, 2022). Instead, traditional approaches like certification schemes and third-party audits continue to play indispensable roles (Tachizawa and Wong, 2014). Our findings further point out that BCT complements these systems: when sustainability questions arise, firms can offer BCT-verified data alongside established certificates. In doing so, BCT reinforces rather than replaces existing trust mechanisms (Yavaprabhas *et al.*, 2022). Therefore, BCT functions as a trust-adding tool; yet current deployments coexist with and do not replace existing governance and manual verification processes. We propose the following:

> *Proposition 2:* BCT enhances information processing capabilities through transparency, immutability, integration, and trust-building in recycling chains. These capabilities can potentially meet the information processing needs at the firm, supply chain, and industry levels.

5.3 Information processing fitting mechanisms

The findings suggest that the BCT-enabled information processing capabilities which we identified do not neatly align with the expectations of technology proponents, as summarized in Table III. This suggests that BCT alone does not necessarily enhance information processing capabilities; rather, additional information processing mechanisms are required.

---Table III about here---

Despite differences in recycling chain structures, product types, sources of uncertainty, and application motivations, all three cases underscore the importance of achieving information processing fit to avoid overload or saturation (Bensaou and Venkatraman, 1995; Srinivasan and Swink, 2018). The prevailing literature suggests that such fit can be realized either by reducing information processing needs or by enhancing information processing capabilities, and that aligning the two supports organizational performance (Aben *et al.*, 2021; Hamann-Lohmer *et al.*, 2023). However, underlying mechanisms are unclear, and it remains unknown about how the fit can adapt to dynamic changes over time (Busse *et al.*, 2017; Tuladhar *et al.*, 2024). Our findings further reveal three fitting mechanisms as Figure 2 shows.

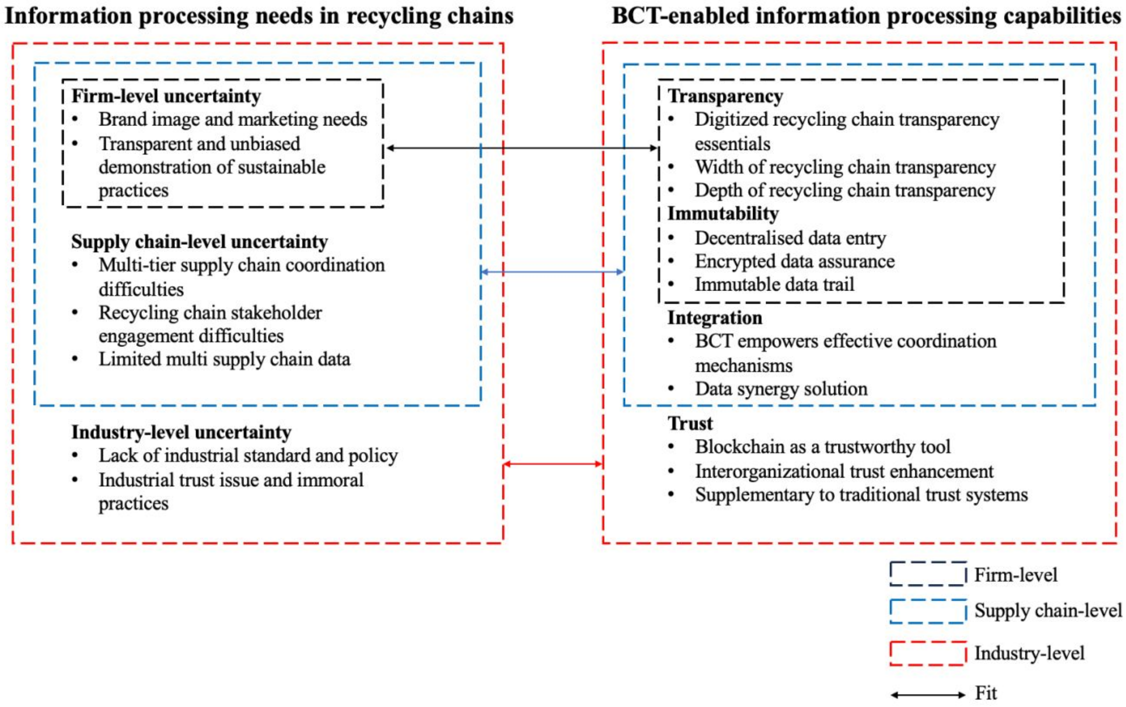

Figure 2 Information processing fit of BCT in recycling chains

The first and most straightforward is *functional fit*, which is similar to the notion of task–technology fit (Chaudhuri *et al.*, 2024). This emphasizes aligning technological capabilities with the specific tasks that users must perform—applying the right technology to the right task. We extend this concept, traditionally studied at the individual level or intra-organizational level (Roth *et al.*, 2023), to the broader multi-tier recycling chain context. Achieving such cross-tier fit requires more than enabling individual actors to use a technology for their own tasks; it entails linking and coordinating activities across multiple stakeholders. For instance, BCT-enabled traceability must capture the entire lifecycle of recycled products, offering visibility across multiple supply chain tiers rather than merely tracking a single stage within a factory.

Second, our study highlights the notion of *contextual fit*. We find that BCT-enabled information processing capabilities do not diminish the core functionalities identified in prior research—such as transparency (Brusset *et al.*, 2024), provenance and anti-counterfeiting (Shen *et al.*, 2022), and trust enhancement (Yavaprabhas *et al.*, 2022). The persistence of these capabilities suggests that, while technical features remain important, research should move beyond cataloguing what BCT can do towards examining the socio-technical conditions that determine its effectiveness in the embedded contexts (Lustenberger and Spychiger, 2025). For example, in recycled plastics, cost and product value constraints mean that traceability is maintained at the batch level rather than at the micro level of individual plastic particles, as is common in luxury goods authentication (Klöckner *et al.*, 2023).

Third, we identify a *systemic fit,* characterized by the interaction of BCT-enabled information processing capabilities across multiple levels of information processing needs. For example, supply chain–level uncertainties may necessitate integration, which, in turn, depends on the focal company's ability to collaborate with partners to acquire, share, and transform timely and accurate information (Lumineau *et al.*, 2021). However, such integration does not arise automatically; it requires data that are authentic, immutable, and transparently collected, as well as a willingness among stakeholders to share them. When organizations face more complex, macro-level information processing needs, such as industry-wide ambiguity stemming from the lack of standardization (e.g., defining what truly qualifies as a recycled product), neither a single technological tool nor a single actor is sufficient. Meeting such needs demands more expansive information processing capabilities.

In general, our findings suggest that simply reducing information processing needs or relying solely on technology to increase processing capabilities does not automatically achieve fit (Bensaou and Venkatraman, 1995; Busse *et al.*, 2017), nor does it necessarily lead to improved organizational performance (Roth *et al.*, 2023). Achieving effective fit requires accurately diagnosing needs within the embedded context, configuring capabilities accordingly, and reinforcing them through appropriate data standards, governance structures, and inter-organizational coordination. Thus, we propose:

> *Proposition 3*: BCT-enabled information processing capabilities cannot automatically meet the information processing needs of recycling chains, and the BCT applications need to take into account functional, contextual, and systemic fit.

6 Conclusions

This research fundamentally explores the recycling chain information processing needs faced by focal companies, and how BCT may help to manage these needs. These information processing needs depend on the specific configuration and structure of multi-tier recycling chains and the type of waste being processed, which manifest multidimensional information processing needs at the firm, supply chain, and industry levels. In this context, BCT emerges as an effective tool with four information processing capabilities, transparency, immutability, integration, and trust.

However, it should be noted that not all expected BCT-enabled information processing capabilities identified in the literature are evident in applications. This discrepancy suggests that the current uses of BCT in recycling are still in their infancy and BCT may not be a panacea; thus, organizations should consider achieving information processing fit through functional, contextual, and systemic mechanisms.

6.1 Research implications

Theoretically, the OIPT lens suggests that greater uncertainty increases information processing needs, which, in turn, requires greater information processing capacity (Galbraith, 1974). However, this linear and static mechanism does not fully capture the complex, multi-level information processing needs inherent in recycling chains. This research makes the following academic contributions: First, our study extends the traditional OIPT view—typically centred on intra-organizational settings (Galbraith, 1974) or dyadic buyer–supplier relationships (Busse *et al.*, 2017; Srinivasan and Swink, 2018) to a broader multi-level recycling chain perspective.

Second, we conceptualize multi-level information processing needs by unpacking recycling chain uncertainties at the firm, supply chain, and industry levels. This perspective enriches prior research that has mainly emphasized micro-level aspects such as task or source uncertainty (Busse *et al.*, 2017; Tushman and Nadler, 1978). By introducing a multi-level uncertainty framework, we demonstrate how interactions across different levels jointly shape information processing needs. In addition, we refine BCT-enabled information processing into four distinct capabilities and examine their interplay with these multi-level uncertainties, offering a more nuanced understanding of the underlying information processing mechanisms.

Third, we contribute to OIPT by introducing three distinct fitting mechanisms—functional fit, contextual fit, and systemic fit (Srinivasan and Swink, 2018; Tuladhar *et al.*, 2024). These mechanisms enrich the traditional view of fit as a single, linear process (Bensaou and Venkatraman, 1995) by demonstrating that alignment can be achieved through multiple pathways and across different levels. Furthermore, while prior research has typically conceptualized fit as a static state, we reframe it as a dynamic adjustment process—an ongoing set of mechanisms rather than a fixed outcome (Martinez *et al.*, 2019; Tuladhar *et al.*, 2024). This perspective underscores that BCT-enabled information processing capabilities cannot be mechanically matched with information processing needs; rather, effective alignment requires functional, contextual, and systemic considerations.

Empirically, this research demonstrates real-use cases applying BCT applications in the multi-tier recycling chains. First, we respond to calls for empirical studies to uncover live BCT applications (Danese *et al.*, 2021; Moraes *et al.*, 2024). This study draws a detailed picture of pioneer BCT applications by using the process mapping technique (New, 2004) to explain how BCT is used, what information needs to be recorded, how to manage data, and how to interact with clients from information processing mechanisms. Second, this study extends the generic BCT discussion by embedding tangible applications that solve real problems in recycling chains (Xie *et al.*, 2023). Third, while many BCT projects have subsequently been stopped or have even failed (Lustenberger and Spychiger, 2025), our study provides a critical perspective on what BCT can realistically offer and how it can be effectively integrated with existing solutions.

6.2 Managerial implications

This study offers managerial insights into effective BCT application in recycling chains. The findings are especially relevant for sustainability managers in brand firms who face increasing information processing needs in ensuring the credibility of sustainability claims while meeting regulatory compliance, and market pressures. By adopting BCT, these managers can strengthen upstream data collection, enhance contract execution, and improve coordination across multiple tiers of recycling networks.

However, rather than positioning BCT as a universal solution, our results underscore the importance of aligning its information processing capabilities with specific organizational needs and operational contexts (Klöckner *et al.*, 2023). Achieving this alignment requires attention to several contextual conditions, such as data standards, stakeholder willingness to share data, and broader organizational and institutional readiness (Moraes *et al.*, 2024). It is also essential for brands to establish cross-organizational coordination mechanisms to support effective governance (Lumineau *et al.*, 2021). This includes the development of shared data protocols, permissioned access systems, and incentive structures tailored to different stakeholders, all of which are critical to meaningful participation and value realization. The supply chain managers may use the framework as a tool to evaluate whether proposed BCT solutions are appropriately designed to meet the organization's specific information processing needs, rather than adopting new technologies for their novelty alone.

We also offer managerial implications for other recycling chain stakeholders. For technology providers, the findings underscore the importance of developing targeted and customer-driven solutions that respond to real-world sustainability and operational challenges, rather than offering generic technological platforms. For suppliers, especially upstream SMEs, BCT can serve as a means to demonstrate compliance and transparency, enhance credibility, and secure stronger partnerships with downstream brand owners—for example, securing larger or longer-term orders. Finally, for verification bodies and industry associations (Danese *et al.*, 2021), BCT offers a complementary infrastructure to strengthen existing supervision and auditing systems. However, its application must be integrated with formal regulatory instruments to ensure standardization, compliance, and credible assessment.

6.3 Limitations and future research

We acknowledge that BCT applications are still in their early stages, and many pioneering pilot programs with potentially richer applications were excluded from our case screening. Identifying these once promising but now stagnant cases could yield valuable practical lessons. The analysed cases highlight that BCT is not a universal solution (Xie *et al.*, 2023), prompting further investigation into how it differs from traditional institutional controls and other technical solutions. This underscores the need for a more critical assessment of BCT's realistic capabilities. Furthermore, transitioning to a CE involves not only recycling but also a broader range of circularity strategies (Ratsimandresy and Miemczyk, 2024), such as reuse and remanufacturing. Adopting this wider perspective opens new opportunities to explore BCT's potential within CE systems. Given the contextual specificity of recycling, future research could explore how BCT-enabled information processing capabilities can be adapted and applied across other industrial sectors or institutional contexts (Chaudhuri *et al.*, 2025; Klöckner *et al.*, 2023) and other information processing mechanisms (Tuladhar *et al.*, 2024). For instance, it could be applied to industries such as pharmaceuticals, where provenance and anti-counterfeiting are paramount; agri-food, where sustainability claims are increasingly scrutinized; and electronics, where granular product-level data are required to comply with digital product passport regulations, all of which present distinct and increasing information processing needs.

We also recognize the limitation of the theoretical elaboration view. The fit between information processing needs from recycling chains and BCT-based information processing capabilities must be considered from a dynamic perspective, as the ongoing scale of application, institutional environment, and supply chain relationships can impact the application performance. We call for further longitudinal and dynamic approaches to validate our findings. By incorporating diverse perspectives, we can deepen our understanding of the real value of BCT in general supply chain management domains.

References

Aben, T.A., van der Valk, W., Roehrich, J.K., & Selviaridis, K. (2021). Managing information asymmetry in public–private relationships undergoing a digital transformation: the role of contractual and relational governance. *International Journal of Operations & Production Management,* 41(7), 1145-1191.

Baralla, G., Pinna, A., Tonelli, R., & Marchesi, M. (2023). Waste management: A comprehensive state of the art about the rise of blockchain technology. *Computers in Industry,* 145, 103812.

Beltagui, A., Gold, S., Kunz, N., & Reiner, G. (2023). Rethinking operations and supply chain management in light of the 3D printing revolution. *International Journal of Production Economics,* 255, 108677.

Bensaou, M., & Venkatraman, N. (1995). Configurations of interorganizational relationships: A comparison between US and Japanese automakers. *Management Science,* 41(9), 1471-1492.

Bhatia, M.S., & Gangwani, K.K. (2025). Towards circular economy: Leveraging blockchain technology for circular supply chain. *Journal of Environmental Management,* 380, 125039.

Bhattacharya, S., Govindan, K., Dastidar, S.G., & Sharma, P. (2024). Applications of artificial intelligence in closed-loop supply chains: Systematic literature review and future research agenda. *Transportation Research Part E: Logistics and Transportation Review,* 184, 103455.

Brookbanks, M., & Parry, G. (2022). The impact of a blockchain platform on trust in established relationships: a case study of wine supply chains. *Supply Chain Management: An International Journal,* 27(7), 128-146.

Brusset, X., Kinra, A., Naseraldin, H., & Alkhudary, R. (2024). Increasing willingness to pay in the food supply chain: a blockchain-oriented trust approach. *International Journal of Production Research,* 62(24), 8858-8879.

Busse, C., Meinlschmidt, J., & Foerstl, K. (2017). Managing information processing needs in global supply chains: A prerequisite to sustainable supply chain management. *Journal of Supply Chain Management,* 53(1), 87-113.

Centobelli, P., Cerchione, R., Vecchio, P.D., Oropallo, E., & Secundo, G. (2022). Blockchain technology for bridging trust, traceability and transparency in circular supply chain. *Information & Management,* 59(7), 103508.

Chaudhuri, A., Bhatia, M.S., Subramanian, N., Kayikci, Y., & Dora, M. (2024). Socio-technical capabilities for blockchain implementation by service providers: multiple case study of projects with transaction time reduction and quality improvement objectives. *Production Planning & Control,* 35(9), 978-991.

Chaudhuri, A., Wæhrens, B.V., Treiblmaier, H., & Jensen, S.F. (2025). Impact pathways: digital product passport for embedding circularity in electronics supply chains. *International Journal of Operations & Production Management,* 45(6), 1213-1226.

Danese, P., Mocellin, R., & Romano, P. (2021). Designing blockchain systems to prevent counterfeiting in wine supply chains: a multiple-case study. *International Journal of Operations & Production Management,* 41(13), 1-33.

de Lima, F.A., Seuring, S., & Genovese, A. (2024). How to enhance circular supply chains? Aligning R-imperatives, uncertainty management and sustainability. *International Journal of Operations & Production Management,* 44(4), 836-858.

Deloitte, (2024). Embracing Digital Product Passport as a regulatory requirement. https://www.deloitte.com/in/en/Industries/consumer/analysis/embracing-digital-product-passport-regulatory-requirement.html.

Denizel, M., & Schumm, C.Z. (2023). Closed loop supply chains in apparel: Current state and future directions. *Journal of Operations Management,* 70(2), 190–223.

Dubois, A., & Gadde, L.-E. (2002). Systematic combining: an abductive approach to case research. *Journal of Business Research,* 55(7), 553-560.

Eisenhardt, K.M. (1989). Building theories from case study research. *Academy of Management Review,* 14(4), 532-550.

European Commission, (2024). Recycling the 10 Rs into circular criteria. https://green-forum.ec.europa.eu/news/news-article-2024-11-28_en?prefLang=cs.

Fisher, G., & Aguinis, H. (2017). Using Theory Elaboration to Make Theoretical Advancements. *Organizational Research Methods,* 20(3), 438-464.

Flynn, B.B., Koufteros, X., & Lu, G. (2016). On theory in supply chain uncertainty and its implications for supply chain integration. *Journal of Supply Chain Management,* 52(3), 3-27.

Galbraith, J.R. (1974). Organization design: An information processing view. *Interfaces,* 4(3), 28-36.

Garrido-Hidalgo, C., Olivares, T., Ramirez, F.J., & Roda-Sanchez, L. (2019). An end-to-end internet of things solution for reverse supply chain management in industry 4.0. *Computers in Industry,* 112, 103127.

Gibbert, M., Ruigrok, W., & Wicki, B. (2008). What passes as a rigorous case study? *Strategic Management Journal,* 29(13), 1465-1474.

Gioia, D.A., Corley, K.G., & Hamilton, A.L. (2013). Seeking qualitative rigor in inductive research: Notes on the Gioia methodology. *Organizational Research Methods,* 16(1), 15-31.

Gong, Y., & Xie, S., (2023). Multi-tier Sustainable Supply Chain Management and Blockchain Technology Solutions, In: Sarkis, J. (Ed), The Palgrave Handbook of Supply Chain Management. Springer International Publishing, Cham, pp. 1-28.

Gong, Y., Xie, S., Arunachalam, D., Duan, J., & Luo, J. (2022). Blockchain-based recycling and its impact on recycling performance: A network theory perspective. *Business Strategy and the Environment,* 31(8), 3717– 3741.

Gregory, R.W., Beck, R., Henfridsson, O., & Yaraghi, N. (2024). Cooperation Among Strangers: Algorithmic Enforcement of Reciprocal Exchange with Blockchain-Based Smart Contracts. *Academy of Management Review,* In press

Hald, K.S., & Kinra, A. (2019). How the blockchain enables and constrains supply chain performance. *International Journal of Physical Distribution & Logistics Management,* 49(4), 376-397.

Hamann-Lohmer, J., Bendig, M., & Lasch, R. (2023). Investigating the impact of digital transformation on relationship and collaboration dynamics in supply chains and manufacturing networks – A multi-case study. *International Journal of Production Economics,* 262, 108932.

Hastig, G.M., & Sodhi, M.S. (2020). Blockchain for supply chain traceability: Business requirements and critical success factors. *Production and Operations Management,* 29(4), 935-954.

Karaer, Ö., & Lee, H.L. (2007). Managing the reverse channel with RFID-enabled negative demand information. *Production and Operations Management,* 16(5), 625-645.

Ketokivi, M., & Choi, T. (2014). Renaissance of case research as a scientific method. *Journal of Operations Management,* 32(5), 232-240.

Klöckner, M., Schmidt, C.G., Fink, A., Flückiger, L., & Wagner, S.M. (2023). Exploring the physical–digital interface in blockchain applications: Insights from the luxury watch industry. *Transportation Research Part E: Logistics and Transportation Review,* 179, 103300.

Lorentz, H., Aminoff, A., Kaipia, R., Pihlajamaa, M., Ehtamo, J., & Tanskanen, K. (2020). Acquisition of supply market intelligence–An information processing perspective. *Journal of Purchasing and Supply Management,* 26(5), 100649.

Lumineau, F., Wang, W., & Schilke, O. (2021). Blockchain governance—A new way of organizing collaborations? *Organization Science,* 32(2), 500-521.

Lustenberger, M., & Spychiger, F. (2025). Blockchain in supply chains: an unfulfilled promise. *Supply Chain Management: An International Journal,* 30(2), 178-194.

Marques, L., Morais, D., & Terra, A. (2025). More than meets the eye: misconduct and decoupling against blockchain for supply chain transparency. *Production and Operations Management,* 34(5), 1057-1075.

Martinez, V., Zhao, M., Blujdea, C., Han, X., Neely, A., & Albores, P. (2019). Blockchain-driven customer order management. *International Journal of Operations & Production Management,* 39(6/7/8), 993-1022.

Meena, R., Sahoo, S., Malik, A., Kumar, S., & Nguyen, M. (2025). Artificial intelligence and circular supply chains: framework for applications and deployment from the triple bottom line model perspective. *Annals of Operations Research,* forthcoming

Moraes, K.K., Ganga, G.M.D., Godinho Filho, M., Santa-Eulalia, L.A., & Tortorella, G.L. (2024). Overcoming technological barriers for blockchain adoption in supply chains: a diffusion of innovation (DOI)-informed framework proposal. *Supply Chain Management: An International Journal,* 30(1), 19-49.

Nativi, J.J., & Lee, S. (2012). Impact of RFID information-sharing strategies on a decentralized supply chain with reverse logistics operations. *International journal of production economics,* 136(2), 366-377.

New, S. (2004). Supply chains: construction and legitimation. *Understanding Supply Chains: Concepts, Critiques & Futures*, 69-108.

Pagell, M., Wu, Z., & Murthy, N.N. (2007). The supply chain implications of recycling. *Business Horizons,* 50(2), 133-143.

Parry, G.C., Brax, S.A., Maull, R.S., & Ng, I.C. (2016). Operationalising IoT for reverse supply: the development of use-visibility measures. *Supply Chain Management: An International Journal,* 21(2), 228-244.

Patton, M.Q., (2002). *Qualitative research and evaluation methods 3rd. ed*. Sage publications

Ratsimandresy, A., & Miemczyk, J. (2024). Facilitating the circular economy: insights from novel supply network actors. *Supply Chain Management: An International Journal,* 29(5), 852-870.

Roth, T., Stohr, A., Amend, J., Fridgen, G., & Rieger, A. (2023). Blockchain as a driving force for federalism: A theory of cross-organizational task-technology fit. *International Journal of Information Management,* 68, 102476.

Saberi, S., Kouhizadeh, M., Sarkis, J., & Shen, L. (2019). Blockchain technology and its relationships to sustainable supply chain management. *International Journal of Production Research,* 57(7), 2117-2135.

Santander, P., Sanchez, F.A.C., Boudaoud, H., & Camargo, M. (2020). Closed loop supply chain network for local and distributed plastic recycling for 3D printing: a MILP-based optimization approach. *Resources, Conservation and Recycling,* 154, 104531.

Shen, B., Dong, C., & Minner, S. (2022). Combating Copycats in the Supply Chain with Permissioned Blockchain Technology. *Production and Operations Management,* 31(1), 138-154.

Siggelkow, N. (2007). Persuasion With Case Studies. *Academy of Management Journal,* 50(1), 20-24.

Srinivasan, R., & Swink, M. (2018). An investigation of visibility and flexibility as complements to supply chain analytics: An organizational information processing theory perspective. *Production and Operations Management,* 27(10), 1849-1867.

Strauss, A., & Corbin, J., (1990). *Basics of qualitative research-Grounded theory procedures and techniques*. Sage Publication

Tachizawa, E.M., & Wong, C.Y. (2014). Towards a theory of multi-tier sustainable supply chains: a systematic literature review. *Supply Chain Management: An International Journal,* 19(5/6), 643-663.

Tuladhar, A., Rogerson, M., Engelhart, J., Parry, G.C., & Altrichter, B. (2024). Blockchain for compliance: an information processing case study of mandatory supply chain transparency in conflict minerals sourcing. *Supply Chain Management: An International Journal,* 29(4), 755-777.

Tushman, M.L., & Nadler, D.A. (1978). Information Processing as an Integrating Concept in Organizational Design. *Academy of Management Review,* 3(3), 613-624.

Van Engeland, J., Beliën, J., De Boeck, L., & De Jaeger, S. (2020). Literature review: Strategic network optimization models in waste reverse supply chains. *Omega,* 91, 102012.

Voss, C., Tsikriktsis, N., & Frohlich, M. (2002). Case research in operations management. *International Journal of Operations & Production Management,* 22(2), 195-219.

Wilhelm, M.M., Blome, C., Bhakoo, V., & Paulraj, A. (2016). Sustainability in multi-tier supply chains: Understanding the double agency role of the first-tier supplier. *Journal of Operations Management,* 41, 42-60.

Xie, S., Gong, Y., Kunc, M., Wen, Z., & Brown, S. (2023). The application of blockchain technology in the recycling chain: a state-of-the-art literature review and conceptual framework. *International Journal of Production Research,* 61(24), 8692-8718.

Yavaprabhas, K., Pournader, M., & Seuring, S. (2022). Blockchain as the "trust-building machine" for supply chain management. *Annals of Operations Research,* 327(1), 49-88.

Zhang, A., Wang, J.X., Farooque, M., Wang, Y., & Choi, T.-M. (2021). Multi-dimensional circular supply chain management: A comparative review of the state-of-the-art practices and research. *Transportation Research Part E: Logistics and Transportation Review,* 155, 102509.

Tables

Table I Technology application in reverse or circular supply chain

Typologies	Specification	Common Applications in Reverse or Circular Supply Chain	Selected studies
Sense and Identification: RFID, Sensors	Enable real-time detection, identification, and tracking of items or environmental conditions, enhancing visibility, traceability, and automation.	• Capture data from RFID tags or sensors as items move through the reverse logistics system. • Use radio waves to automatically identify and track items or packaging.	(Karaer and Lee, 2007; Nativi and Lee, 2012)
Connection, Storage, and Communication: IoT, Cloud	Provide digital infrastructure for real-time data transmission and integration among devices, systems, and supply chain actors.	• Enable real-time data exchange on item condition, location, and movement. • Support integration with systems such as inventory, customer service, and regulatory platforms. • Use cloud computing to store data on return volumes, conditions, transactions, and inspections.	(Garrido-Hidalgo *et al.*, 2019; Parry *et al.*, 2016)
Production: 3D printing	Facilitate on-demand, modular production using additive manufacturing for reuse, repair, and remanufacturing.	• Use recycled materials to produce or redesign components for improved repairability and circularity, supporting reverse supply chain strategies.	(Beltagui *et al.*, 2023; Santander *et al.*, 2020)
Data Analytics: Big Data Analytics, AI, Machine learning	Analyse large, complex data sets to generate predictive insights and support strategic decision-making in reverse logistics.	• Apply AI for automated decision-making, sorting, forecasting, optimization, and planning across repair, reuse, remanufacturing, and recycling workflows. • Optimize reverse network design and routing with predictive Big Data analytics. • Use machine learning to analyse return behaviour and detect fraud.	(Bhattacharya *et al.*, 2024; Meena *et al.*, 2025)
Blockchain technology	Provide a secure, decentralized, and immutable ledger for recording and verifying transactions, enhancing traceability, transparency, and trust in multi-tier reverse supply chains.	• Ensure tamper-proof documentation of recycled material provenance and custody chains. • Enhance transparency and auditability of reverse logistics activities across multiple stakeholders. • Provide token-based incentives for material return and waste collection. • Enable smart contract automation for verification, payment, or compliance in reuse and recycling processes.	(Baralla *et al.*, 2023; Saberi *et al.*, 2019; Xie *et al.*, 2023)

Table II Data collection information

Case	Headquarters & main operations	Industry & Waste type	Multi-stakeholder role	Affiliated with organization, Code names, and interview details	Additional sources
Alpha	the Netherlands, China, India	Textile industry, plastic waste	Focal company	General Manager (A1): • 12 Nov 2021 (60 mins, face to face)	• Online webinars participation (88 min), • Recycled product description (18 pages), • Association recycled plastic certification guide (10 Pages), • Recycled fabric and garment video (34 min) • On site visit of recycled product testing lab (1 hour) • Product samples.
			Focal company	R&D Blockchain Director (A2): • 23 Nov 2021 (40 mins), Face to face • 17 Feb 2022 (90 mins), Face to face • 11 Jan 2023 (40 mins), Online	
			Focal company	Blockchain Manager (A3): • 16 Jan 2022 (85 mins), Face to face • 16 Feb 2022 (90 mins), Face to face	
			Tier 1 Supplier	CEO (A4) • 25 Mar 2022 (70 mins), Online • 26 Mar 2022 (50 mins), Online	
			Tier 2 Supplier	CEO (A5) • 13 Nov 2021 (40 mins), Online • 12 Apr 2022 (70 mins), Online	
			Tier 3 Supplier	General Manager (A6) • 28 Aug 2022 (35 mins), Online	
Beta	UK, China	Fast fashion industry: Textile waste	Blockchain provider	IT Developer (B1) • 3 Nov 2021 (60 mins), Face to face	• Products introduction (80 Pages), • Project protocol proposal (25 Pages), • Data integration plan slides (9 Pages),
			Blockchain provider	CTO (B2), General Manager (B3): • 4 Nov 2021 (60 mins), Face to face	
			Blockchain provider	Project Manager (B4): • 4 Nov 2021 (60 mins), Face to face • 9 Nov 2021 (90 mins), Face to face • 5 June 2022 (35 mins), Online • 26 Nov 2022 (60 mins), Online	
			Blockchain provider	Co-founder (B5): • 12 Dec 2022 (60 mins), Face to face	

			Blockchain provider	Project member (B6) • 25 Jan 2024 (70 mins), Face to face	• Data feeding guide documents (11 Pages) • Data verification guide documents (13 Pages), • Verification company scope introduction (20 Pages)
			Blockchain provider	Project member (B7) • 29 Jan 2024 (120 mins), Face to face	
			Verification company	Director of Digital Business (B8) • 23 Oct 2022 (76 mins), Online • 23 Jan 2024 (60 mins), Face to face	
			Focus group	Verification Company- Director of Digital Business (B8), Recycling Association-General Manager (B9) • 30 Oct 2022 (100 mins), Online	
Gamma	Denmark, Indonesia	Ocean waste industry: Ocean plastic waste	Blockchain provider	Project Manager (G1) • 4 Nov 2021 (35 mins), Face to face	• Online webinar participation (60 min), • Ocean waste collection introduction video (20 min), • Internal project report (18 Pages), • Code of conduct report (4 Pages) • Public sustainability responsibility report (19 Pages), • Verification scope introduction (16 Pages)
			Blockchain provider	General Manager (G2) • 31 Mar 2022 (40 mins), Face to face • 23 Aug 2022 (55 mins), Online	
			Focal company	General Manager (G3) • 8 Mar 2023 (63 mins), Online	
			Focal company	Data Analyst (G4) • 3 Nov 2022 (60 mins), Online • 6 Dec 2022 (37 mins), Online • 5 Feb 2023 (64 mins), Online	
			Verification company	General Manager (G5) • 23 Feb 2023 (60 mins), Online	
			Workshop	Blockchain Company-project manager (G6), and External Experts • 11 Jul 2023 (60 mins), Face to face	

Table III Blockchain-enabled Information Processing Capabilities: Expectations versus Applications

Different levels of information processing needs	**Specification of information processing needs**	**What BCT-based information processing capabilities are expected to offer**	**What BCT-based information processing capabilities offer from the cases**[3]
Firm-level uncertainty • Brand image and marketing needs • Transparent and unbiased demonstration of sustainable practices	Focal companies face external sustainability pressures but often lack the necessary information processing capacity. They are expected to provide credible and compelling information to substantiate their sustainability claims and practices.	• BCT is expected to offer transparent information to prove the use of recycled materials (Xie *et al.*, 2023).	• BCT-enabled transparency varies in depth and granularity depending on recycling chain structure, application objectives, and governance arrangements.
		• BCT is expected to show immutable records of recycling chain information (Bhatia and Gangwani, 2025).	• BCT alone does not guarantee immutability; it requires complementary verification and data-feeding mechanisms.
		• BCT is expected to monitor upstream suppliers' sustainable practices and ensure compliance requirement for downstream customers (Marques *et al.*, 2024; Saberi *et al.*, 2019).	• Large-scale "permissionless" systems linking multiple network nodes are rarely feasible in commercial settings.
Supply chain level uncertainty • Multi-tier supply chain coordination difficulties • Recycling chain stakeholder engagement difficulties • Limited multi-tier supply chain data	Focal companies often lack comprehensive data on recycling chains, and this fragmentation hampers the effective integration and coordination of multi-tier recycling chains.	• BCT is expected to serve as an interface capturing full recycling chain activities (Baralla *et al.*, 2023).	• Effective BCT-enabled integration depends on physical–digital connectivity and stakeholders' willingness to share data. Current connectivity is mostly QR code–based, with more advanced data-capture tools still emerging.
		• Processed information can support regulatory compliance and inspections (Danese *et al.*, 2021).	• Integration typically occurs at the batch level for specific products or recycling chains, not across entire supplier databases. • Data-sharing arrangements and permission controls remain critical.

---

[3] These contents illustrate the shared patterns across the cases.

Industry-level uncertainty • Lack of industrial standard and policy • Industrial trust issue and immoral practices	Focal companies seek standardized and trustworthy solutions to address counterfeiting and overcome trust deficits within the industry.	• BCT is expected to deliver "trust-free" mechanisms offering novel, standardized practices (Yavaprabhas *et al.*, 2022).	• Perceptions of BCT's trust-enhancing effect vary. The extent of improvement is ambiguous, and alternative trust-building approaches remain viable.
		• BCT is expected to provide self-certification solutions without third-party involvement to boost inter-organizational trust (Centobelli *et al.*, 2022).	• BCT does not fully replace traditional third-party certifications or paper-based documentation.