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Exploring Supply Chain Visibility for Circularity: A Delphi Approach

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ABSTRACT

Circular supply chains (CSCs) depend on enhanced supply chain visibility (SCV) to track and manage resource flows and thereby enable efficient decision-making. Despite confronting silo mentalities, fragmented information, technological barriers, resistance to change, and a lack of standardization, data sharing remains crucial for SCV and circularity. In this study, following the Delphi method, 22 experts explored SCV for circularity, identified 11 circular economy (CE) strategies and 16 critical data elements for implementing CSCs, and assessed data accessibility and the willingness to share data among supply chain actors. Findings show that the experts especially prioritized CE strategies and data elements that support existing business models and forward supply chains. Although those data elements are critical for SCV, they are primarily used for planning internal operations and thus not readily shared with external partners. Such insights contribute to empirical evidence and managerial perspectives and can also help managers to plan SCV tailored to CE strategies.

1 | Introduction

In today's business landscape, driven by the critical problems of resource depletion and negative environmental impact, sustainability has become imperative for organizations (Farrukh et al. 2022). Traditional supply chain models that often rely on a linear "take, make, dispose" approach contribute considerably to those problems by generating waste and being incapable of optimizing resource use (Burke et al. 2023). For an alternative, businesses seek out strategies that both support environmental responsibility and sustain economic performance. One such strategy is adopting circular supply chains (CSCs) (Pesce et al. 2024), which are closely associated with the principles of circular economies (CEs). Briefly put, CEs offer a transformative framework for managing resources more efficiently through reusing, remanufacturing, and recycling within closed-loop systems (Kristoffersen et al. 2020). By moving away from

traditional models of consumption, businesses can realize both environmental and economic benefits.

CSCs represent a shift from the traditional linear approach by encouraging resource efficiency and minimizing waste. Those methods are based on CE strategies (Hazen et al. 2020), which stress the need to maintain the value of resources for as long as possible through practices such as repairing, remanufacturing, and recycling. However, operationalizing such CE strategies requires an understanding of complex flows of materials, information, and data, as well as collaboration across multiple partners and stakeholders. In particular, information and data sharing offers the required supply chain visibility (SCV) by allowing the tracking and management of materials, products, and resources throughout their life cycles (Junaid et al. 2024). For instance, tracking the origin, condition, and composition of materials allows businesses to make informed decisions about how to effectively manage their

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resources. By enabling SCV, those capabilities are especially important for CSCs aimed at maximizing resource efficiency via closed-loop processes (Agrawal et al. 2024).

In supply chains, *visibility* describes the degree to which participants can access timely, accurate information that is valuable, if not vital, for their operations (Somapa et al. 2018). Because such information is derived from data, data are essential for achieving SCV. However, the fine line between data and information in the context of SCV lies in the critical transformation process that converts raw data into contextualized, actionable information capable of generating true visibility. In that context, data serve as the crucial enabler of SCV by creating the informational infrastructure required for comprehensive material traceability and decision-making across complex supply chain networks. By extension, data integration capabilities enable the cross-functional collaboration and technological integration that are required to achieve comprehensive visibility. Supply chains also require robust mechanisms for data collection and data sharing in order to track material flows, monitor details about product life cycles, and improve rates of recycling, reuse, and remanufacturing. Data quality and standardization are critical factors as well, for poor data quality and supply chain complexities present significant challenges to realizing the full benefits of visibility-focused initiatives (van Schilt et al. 2024).

Altogether, data-driven SCV offers insights into identifying opportunities to minimize waste, enable real-time monitoring, manage life cycles, perform predictive analytics, make informed decisions across stakeholders in the supply chain, and implement circular approaches. For example, SCV can reveal where and how materials can be reused and thereby prevent unnecessary waste and prolong their value (Tseng et al. 2022). However, the transition from linear to CSCs requires information about product life cycles, starting with upstream information related to raw material extraction, all the way to downstream information related to end-of-life management, including manufacturing and product transformation processes, transportation, energy consumption, and waste generation and handling at each stage of the supply chain (Bals et al. 2024). With such information, SCV can further enable the identification and optimization of circular material flows and reverse logistics flows.

Regardless of SCV's potential, achieving the visibility needed to implement CSCs confronts problems ranging from a lack of coherent systems for managing information (Henninger and Mashatan 2021) to firm boundaries that give rise to silos and silo mentalities (Hofstetter et al. 2021). Technological limitations also pose a significant challenge. Many businesses, especially small and medium enterprises, lack access to the advanced technology needed to share information for effective SCV, including blockchain, the Internet of Things, and big data analytics (Al-Khatib 2022). Such advanced technology, though important for realizing the level of visibility necessary for CSCs, is often costly (Nandi et al. 2021). Beyond that, concerns over data security, intellectual property, and competitive advantage limit organizations' readiness to reveal or share critical data, which further complicates efforts to enhance SCV.

In this study, authors aimed to address those challenges by investigating how SCV can aid circularity in supply chains. They

focused on both identifying the data and data requirements needed to implement CE strategies and on evaluating data accessibility, the importance and priority of different CE strategies as perceived by experts, and actors' willingness to share data within SCs. In doing so, authors sought both to clarify the correlation between the determinants of SCV (i.e., data elements) and CE strategies and to offer actionable insights for businesses. In the process, they wanted to address the mentioned challenges by identifying the data elements that are critical to enhancing visibility in supply chains to implement CE strategies. The specific objectives were:

- To determine the types of data needed to implement circular strategies:
- To understand the extent to which those data elements are accessible to supply chain actors and actors' willingness to share them with partners or stakeholders;
- To map the identified data elements to specific CE strategies, including repair, refurbishment, and recycling, to provide practical guidance for implementation

This study followed the Delphi method, which is a structured, iterative process designed to establish consensus among experts on complex topics (Campbell-Johnston et al. 2021). By engaging multiple rounds of questioning, from initial open-ended enquiries to investigate broad themes followed by successive rounds with sharpened focus, the method ensures that the outcomes are robust and reflect diverse perspectives. The expert panel for this study consisted of 22 individuals with extensive experience in supply chain management and sustainability in the automotive, electronics, and consumer goods industries, among others. By systematically refining the experts' inputs over five rounds of questioning, the Delphi method in this study enabled the identification of key data elements and strategies that support circularity.

The findings contribute to the growing body of knowledge on SCV and CEs by providing empirical evidence on the critical data elements required for CSCs. They also address the challenges of achieving SCV and provide practical recommendations for overcoming them. In addition, they showcase the importance of collaboration, standardization, and technological innovation in advancing CSCs.

In what follows, Section 2 provides a background on SCV and CEs that highlights key gaps and areas for further exploration. Section 3 describes the Delphi method and its application in this study, after which Section 4 presents the findings, including the identified data elements and their connections to circular strategies. Section 5 discusses the findings and explores their implications for both research and practice. Last, Section 6 concludes the article by summarizing the study's contributions and identifying directions for future research.

2 | Literature Review

2.1 | Supply Chain Visibility

Of the many definitions of SCV in the literature, Barratt and Oke's (2007)—one of the most popular and well cited—describes “the extent to which actors within a supply chain have

access to or share information which they consider as key or useful to their operations and which they consider will be of mutual benefit.” Over the years, SCV has evolved beyond merely referring to supply and demand data to encompassing an array of critical information across the entire supply chain. Various supply chain data, including transactional records, readings from different sensors, and carbon emissions, need to be validated, aggregated, integrated, processed, analyzed, and interpreted to obtain meaningful actionable information that should be further shared among actors to achieve SCV. Including such information makes SCV all the more useful in risk management, especially for the early detection and management of deviations and for controlling supply chain materials, information, and payment flows from the suppliers to end customers (Al-Khatib 2022). It also enhances customer service by allowing products to be tracked and by enabling fact-based decision-making for operational and strategic activities (Carlsson and Nevzorova 2025).

Nevertheless, achieving SCV has always been challenging due to the lack of accurate, consistent, timely data voluntarily provided by supply chain actors. Implementing and establishing SCV systems also require a high degree of trust among actors and support from top management (Agrawal et al. 2024). Other limitations to achieving SCV include a lack of standardization in tools, systems, and technical standards, along with supply chain complexities and inadequate IT infrastructure that hinders SCV. Added to understanding its drivers and challenges, the most important aspects of SCV are data accessibility and the use of information to enhance supply chain performance (Somapa et al. 2018). The literature also indicates that SCV requires various data elements (Sodhi and Tang 2019) and emphasizes the importance of gaining further insights into those elements (de Oliveira and Handfield 2019). When Agrawal et al. (2024) identified, ranked, and categorized data elements for SCV in linear supply chains, the three chief categories were related to customers (e.g., delivery status and prompt deviations), internal operations (e.g., inventory levels at all locations and production capacity in factories), and suppliers (e.g., supplier locations regarding manufacturing and inventory). The ability to track such data was underscored as well, particularly the ability to monitor the movement of materials and parts in real time (Kalaiarasan et al. 2022).

Last, SCV has several capabilities (e.g., predictive and planning capabilities) and effects on performance, including supporting decision-making. As such, it has emerged as a key solution that aids organizations in developing resilience, executing better control over processes and actors, and contributing to effective resource utilization and improved productivity. Even so, the literature predominantly explores SCV in linear supply chains and its role in risk management, customer satisfaction, and resource management. As a consequence, a noticeable gap exists in understanding SCV in CSCs and its potential to facilitate the transition toward CEs (Agrawal et al. 2024).

2.2 | Supply Chains and Circular Economies

In the past few decades, scholars and industry practitioners have increasingly focused on the transition toward CEs, which are

conceptualized as restorative, regenerative systems designed to keep resources at their highest possible value (Bals et al. 2024; Batista et al. 2018; Geissdoerfer et al. 2017). ISO standard 59,004:2024 defines a *circular economy* as “an economic system that uses a systemic approach to maintain a circular flow of resources by recovering, retaining, or adding to their value, while contributing to sustainable development.”

To operationalize the circular flow of resources, a variety of strategies, commonly called “R-strategies,” have been proposed—refusing, rethinking, reducing, reusing, repairing, refurbishing, remanufacturing, repurposing, recycling, and recovering—all ranked according to their relative contribution to circularity (Potting et al. 2017). Among them, the first three strategies (i.e., refusing, rethinking, and reducing) correspond primarily to forward supply chain flows because they promote circularity through smarter product usage and manufacturing. Such actions occur when products are conceived, designed, and developed in ways that enable other CE strategies (Morsetto 2020). The remaining strategies contribute to circularity by extending the use and lifespan of products, components, and materials or, in the case of the strategy of recovering, through energy recovery. Those strategies therefore involve reverse flows (i.e., “circular resource flows”), the implementation of which requires the reconfiguration of traditional supply chains and their associated processes.

A CSC, for instance, encompasses both closed-loop and open-loop configurations (Farooque et al. 2019). In a closed-loop design, returned products and recovered parts or materials are reintegrated into the original equipment manufacturer's (OEM's) supply chain. By contrast, in an open-loop design, the circular resource flows are conducted and managed by independent actors outside the OEM's control (Kalverkamp 2018). Those actors may operate within the same industrial sector as the OEM or across different sectors (Weetman 2016). Both CSC configurations rely on effective coordination between forward and reverse flows and among supply chain actors to enable value creation, delivery, use, recovery, and reuse (Amir et al. 2023; Roci et al. 2022). Such coordination depends on SCV, achieved through data and information sharing across both forward and reverse supply chain processes and actors.

2.3 | How SCV Enables Circularity

SCV is widely recognized as a foundational enabler and driver for the adoption of CEs (Junaid et al. 2024). That trend is exemplified by the recent introduction of digital product passport (DPP) regulations, which underscores SCV's centrality by mandating the exchange of detailed supply chain information to promote CEs at scale (Jensen et al. 2023). In managing the circular flow of resources, the traceability of materials, components, and products across their life cycles is essential (Carlsson and Nevzorova 2025; Quayson et al. 2023). For instance, recycling electric vehicle batteries requires granular data about battery composition, which is critical for realizing circular ambitions (Sorooshian et al. 2024). Bellini et al. (2024) have additionally emphasized that continuous tracking and processing quality data are both needed to facilitate the dynamic monitoring of circular processes and thereby reduce

waste and optimize resource recovery. Meanwhile Riggs et al. (2024) have underscored that vital parameters such as cost, value recovery, and return on investment should be integrated into planning data to enable CE adoption. Technology such as big data, blockchain, and the Internet of Things also enhances traceability and resource management, enables supply chain information sharing, and improves SCV for the transition toward sustainable CSCs (Lin et al. 2025; Neri et al. 2023). SCV additionally supports compliance with environmental regulations and strengthens stakeholder trust, both of which are vital for CE transitions (Hernandez Marquina et al. 2024; Jensen et al. 2023). Beyond that, supply chain integration enabled by SCV mitigates risks while building the confidence of stakeholders in CE strategies and transitions (Pellegrino et al. 2025).

Effectively implementing CE strategies critically depends on comprehensive, high-quality data sharing across product life cycles and supply chains in forward and reverse flows (Bjerre and Parbo 2021). Past research has highlighted different types of data and their relevance for successfully implementing different CE strategies. Morsetto (2020) has highlighted that strategies of refusing and rethinking are closely connected to design and that sharing design and engineering data can help to implement those strategies. Similarly, sharing data on the use of input resources (e.g., raw material, energy, and water) and outputs (i.e., waste and emissions) can help to implement strategies of reducing. While exploring the data needed for decision-making about product life cycles, Jensen et al. (2023) identified 28 data points, clustered into seven categories: usage and maintenance, product identification, product and materials, guidelines and manuals, supply chain and reverse logistics,

environmental data, and compliance data. The authors emphasized the data needed by actors in a CSC in order to support decision-making about product life cycles considering both the forward-oriented and reverse supply chain. Apeji and Sunmola (2022) have also categorized principles that influence visibility in sustainable contexts and specifically substantiated findings on why certain sustainable or circular data elements are more readily shared than internal operational data. In a literature review, Acerbi et al. (2021) have also identified managerial, product-, process-, and technology-related data elements for the adoption of different circular manufacturing strategies. A comprehensive list of different data elements mapped to CE strategies, mostly related to R-strategies in the literature, appears in Table 1.

Table 1 shows that despite growing attention on SCV and CSCs in the literature, few empirical studies have examined their interrelationships. According to Taddei et al. (2024), a major barrier to adopting CSCs is the absence of a shared vision among supply chain actors regarding CE strategies. Overcoming that barrier requires the collaborative co-creation and prioritization of CE strategies, supported by integrated technology solutions and information sharing, all to align objectives and drive successful CSC implementation. Meanwhile, Bellini et al. (2024), while analyzing data's role in implementing CE strategies and highlighting future trends for CE, have pinpointed the need for data governance and management. Successfully implementing CE also requires holistic digital transformation supported by strong data governance, in accordance with linear supply chain information sharing and utilization (Jonsson and Myrelid 2016). Those authors also highlight that ensuring data accessibility and the willingness to share data are critical

TABLE 1 | Data elements mapped to different circular economy (CE) strategies in the literature.

CE strategy	Key data elements	Relevant references
Refusing and rethinking	Product design specifications (e.g., schematics and bill of materials [BoM]); material composition; environmental impact assessments	Morsetto (2020)
Reducing	Material, energy, and water use per unit; process yields; data on waste generation; emissions data	Moraga et al. (2019), Morsetto (2020)
Reusing and repairing	Product condition and grading data; usage history and data; test and inspection results; maintenance and repair history; service manuals and disassembly guidelines; spare parts inventory status	Bressanelli et al. (2018), Fontana et al. (2021), Jensen et al. (2023)
Refurbishing and remanufacturing	Product usage data; product type; product model; product design specifications (e.g., schematics and BoM); design tolerances and critical dimensions of components; information about component manufacturers; material composition; process parameters	Acerbi et al. (2021), Goodall et al. (2019)
Repurposing	Traceability data; item quality after use; disassembly instructions; compliance; inventory data; item tracking	Bjerre and Parbo (2021), Carlsson and Nevzorova (2025), Jensen et al. (2023)
Recycling	Traceability data; product usage and quality; degradation tracking; recycling infrastructure and location	Araujo et al. (2025), Dahmus and Gutowski (2007), Jensen et al. (2023), Lase et al. (2022)

and that organizations have to strategically assess their CE-oriented data needs, use, ownership, and sharing protocols, even if such approaches are largely absent in the literature. In other research, Agrawal et al. (2024) have mostly examined SCV-related data elements for linear supply chains; Jensen et al. (2023) have focused on SCV-related data for specific policy instruments such as DPPs that promote CEs; and Carlsson and Nevzorova (2025) have acknowledged the growing trend of attributing data and information to material items in order to enable circular flows.

In this study, authors first identified and prioritized different CE strategies from the perspectives of supply chain experts. Considering those strategies, they next identified and mapped critical data elements required for their implementation. After that, they examined data governance by mapping the accessibility of those data elements among supply chain actors and assessed the willingness of businesses to share them with partners and stakeholders. Last, they developed a unified framework for implementing circular flows of resources supported by relevant data elements.

3 | Methodology

This study followed the Delphi method as a means to assess managerial perspectives on SCV and examine SCV's role in facilitating product and material circularity. Originally developed by Dalkey and Helmer (1963) at the RAND Corporation, the Delphi method is a well-established technique for systematically gathering expert-based empirical data in order to reach consensus on complex, multidisciplinary topics. In the method, a panel of experts with extensive subject-matter knowledge participate in multiple rounds of questioning with their anonymity maintained to mitigate biases and conflicts. Whereas experts respond to open-ended questions in the initial round to explore the topic and generate new concepts, subsequent rounds can involve ranking or rating previously derived constructs. Thus, the responses from each round provide input for the subsequent round, which allows participants to reflect on the aggregated results—typically presented through measures such as means and dispersion—and, if appropriate, revise their answers. The iterative process gradually reduces bias and minimizes unproductive disagreements. In general, Delphi studies facilitate the gathering of insightful perspectives from industry practitioners and experts to develop exploratory theory, make decisions, identify best practices, and examine interdependencies. Past studies in supply chain management have used the method to investigate information sharing (Kembro et al. 2025), digital transformation (Berbel-Vera et al. 2022), risks and uncertainties in CSCs (De Lima and Seuring 2023), and producer responsibilities in CEs (Campbell-Johnston et al. 2021). Considering all the above, authors identified the Delphi method as a suitable means for exploring managerial perspectives on the relationship between SCV and CE strategies and aligning them with the needed data.

This study began with the recruitment of the appropriate experts who provided their input over five consecutive rounds of questioning between August 2023 and October 2024, as described below. During each round, experts were given 4–6 weeks

TABLE 2 | Summary of rounds of questioning in the Delphi study.

Steps	Purpose
Expert selection	To form a panel with experts representative of manufacturing companies and with extensive industry experience
Round 1	To explore perspectives on circular economy (CE), key strategies, and practices
Round 2	To explore the need for data elements for circularity
Round 3	To prioritize and rank CE strategies and link them with key data elements for supply chain visibility (SCV) in order to identify the most critical ones for circularity
Round 4	To conduct focus group webinars to verify rankings of CE strategies, refine links to SCV-related data elements, and capture expert reflections for further analysis
Round 5	To assess data accessibility and businesses' willingness to share the identified SCV-related data elements

to respond to the questionnaire, and a reminder email was sent 2 weeks before the deadline to ensure maximum timely responses. Each step in the study is summarized in Table 2 and detailed in Sections 3.1–3.6.

3.1 | Creating the Expert Panel

To establish a panel of experts with a thorough understanding of the research topic (i.e., CEs and SCV) and who could provide various viewpoints to ensure the validity of the results, authors followed the general guidelines for Delphi studies (Kembro et al. 2025). The recruitment of experts began by inviting supply chain and sustainability executives from manufacturing industries with a global footprint that represented various sectors (e.g., telecommunications, automotive, aerospace, and furniture). The invitation email included an overview of the Delphi method along with a clarification that the study would be conducted in multiple rounds and would conclude once consensus was reached.

In the Delphi method, an ideal panel has 20–30 experts (Ogden et al. 2005); a minimum of 20 experts helps to reduce the possibility that individual bias will distort the aggregate responses, whereas having fewer than 30 experts ensures that the group remains manageable and allows the deeper exploration of emerging insights. Approximately 50 executives were invited to participate in the study, and 22 experts ultimately agreed to participate. Each expert had extensive experience and knowledge related to the topic and worked for a globally recognized company with production units worldwide.

All experts were managing global supply chain and sustainability operations at a strategic level in different locations in Europe and abroad. The companies selected were not merely OEMs or focal companies in supply chains but represented a mix of OEMs and suppliers to major OEMs, which ensured perspectives from different actors in the supply chain. A detailed description of the experts' profiles appears in Table A1 in the Appendix. It can be noted that the panel's composition demonstrated appropriate stability across the five rounds. Out of the 22 experts who participated in Round 1, 20 remained through Rounds 2 and 3 (i.e., 91% retention). Round 4, being a focus webinar, saw participation from 18 experts (i.e., 82% of the original cohort) because other experts had scheduling conflicts. Nevertheless, Round 5 had 21 participants (i.e., 95.5%), indicating that a previously absent expert re-engaged in the final round. The overall retention rate of 82%–95.5% across the rounds suggests the experts' continuous commitment to the research objectives.

3.2 | Round 1: Exploring experts' perspectives on CE

Round 1 sought to understand the experts' perspectives on CE and explore key strategies and practices aligned with CE principles. The invitation letter provided an overview of the study, described its scope and timeline, assured anonymity throughout the process, and included four open-ended questions:

1. What does *circularity* mean to you, your company, and your supply chains?
2. Why is circularity important to your company and your supply chains?
3. What factors affect or are affected by the circularity of your supply chains, and how?
4. Is there anything else that you think is important in the context of circularity and supply chains that you would like to add?

All responses to those questions were compiled into a single Word document that totaled approximately 7800 words. Authors conducted independent content analyses to identify a list of keywords and to identify and categorize common phrases. To facilitate categorization, they adopted the ABCDE framework by Kalaiarasan et al. (2022), which includes antecedents, barriers, challenges, drivers, and effects (i.e., capabilities and performance outcomes).

3.3 | Round 2: Understanding the Need for Data for Circularity

Based on the responses and content analysis from Round 1, a list of perspectives on circularity and related challenges was compiled. The challenges were clustered, and three themes emerged from the clustered data: product-related challenges (e.g., product design, disassembly, and packaging), process-related challenges (e.g., materials handling and recycling location), and supply chain-related challenges (e.g., mode of transport, reverse logistics, and fill rate).

In Round 2, the experts were asked to validate the responses from Round 1 and further explore SCV-related information deemed vital to fostering circularity in supply chains. Experts were also asked to describe how SCV, particularly in terms of data sharing, can address challenges in each of the three emerging themes (i.e., challenges) and the effects that the SCV-related data would have on supply chain circularity. The results were compiled and saved in another Word document totaling approximately 2500 words. Authors conducted a content analysis that resulted in the mapping of 23 SCV-related data elements needed for 11 CE strategies. Clustering challenges, mapping data elements, and clustering CE strategies were all undertaken following the Gioia data analysis method, meaning that the themes and strategies emerged inductively to ensure rigor and transparency.

3.4 | Round 3: Prioritizing and ranking strategies and practices

Round 3 had two objectives: to identify and rate the top CE strategies among the 11 recognized strategies in Round 2 and to identify the relationship between the SCV-related data elements and top-rated CE strategies. To that end, experts were sent an Excel spreadsheet containing the 11 identified CE strategies on Sheet 1 and, on Sheet 2, a 23×11 matrix of 23 data elements mapped to 11 CE strategies. The first task, on Sheet 1, was to rate each CE strategy on a scale of 1 to 5 based on importance (5 = *very important*, 3 = *indifferent*, 1 = *unimportant*). Then, on Sheet 2, using a ticking option, experts were asked to select the cell of the matrix corresponding to data elements that they deemed necessary for each CE strategy. Authors compiled and analyzed the experts' responses in order to calculate the mean, standard deviation, median, and mode for each strategy. The analysis enabled the visualization of the prioritized CE strategies and their links to crucial SCV-related data elements that should be recorded and shared within the supply chain to effectively implement them.

Following Round 3 of expert evaluation, 16 of the 23 identified data elements were retained for subsequent rounds of analysis based on expert consensus. Seven data elements were thus excluded from further consideration, because they received support from only one expert or no experts at all. To ensure analytical focus on the most critical data elements and reduce methodological complexity, a threshold criterion was established in which data elements required support from at least two experts to advance to subsequent rounds. The elimination of those seven data elements was subsequently validated during the expert webinars, in which all participating experts unanimously confirmed the appropriateness of their exclusion from further analysis.

3.5 | Round 4: Focus Group Webinars

Round 4 was organized as two focus group webinars in order to enable maximum participation. During the webinars, key results from each round were presented, and special focus was given to verifying and further discussing the results from Round 3, specifically the ranking of the CE strategies and their link to

SCV-related data elements. The reflections, discussions, and commentary provided by the experts were noted, and the webinars were recorded and used to clarify and develop arguments during the discussion of the results. Another chief objective of the expert webinars was to systematically explore and analyze areas of persistent disagreement among experts regarding specific CE strategies and data elements; such divergences in expert opinion are methodologically recognized phenomena in Delphi studies, in which low consensus can emerge despite multiple iterative rounds (Pal et al. 2018).

Incorporating facilitated webinars constituted a methodological enhancement to the conventional Delphi method that enabled in-depth qualitative exploration of dissenting viewpoints. The interactive format provided valuable insights into the underlying rationale and contextual factors driving expert disagreements, thereby enriching the study's analytical depth and offering a nuanced understanding of areas in which professional consensus remains elusive. The discussion in the webinars revealed that disagreements often stemmed from varying industry contexts, regulatory environments, and implementation priorities rather than from fundamental conceptual differences. The discussions provided important contextual information that quantitative rounds alone could not capture.

3.6 | Round 5: Understanding Accessibility and the Willingness to Share Identified SCV-Related Data Elements

Last, Round 5, motivated by the results from the webinars, focused on exploring and understanding the accessibility of and willingness to share the identified SCV-related data elements. During Round 5, the experts were sent a new Excel spreadsheet to provide insights on the status of the SCV-related data. Similar to Round 3, they were asked to rank each SCV-related data element on a scale of 1 to 5 for accessibility (5 = readily available, 1 = not available).

TABLE 3 | Expert ($n=22$) ratings of circular economy (CE) strategies on a 5-point Likert scale ranging from 1 (least important) to 5 (most important) that informed the hierarchy of CE strategies.

CE strategy	M	Median	Mode	IQR	SD	Importance
Reducing/eliminating waste	4.67	5.0	5	0.75	0.65	High
Resource efficient production	4.50	5.0	5	1.00	0.80	High
Repairing	4.42	5.0	5	1.00	1.16	High
Transport efficiency	4.42	5.0	5	1.00	1.16	High
Recycling	4.25	5.0	5	1.75	1.06	High
Refurbishing	3.75	4.0	5	2.00	1.48	Moderate
Modularization/flexible product design	3.67	4.0	5	2.00	1.29	Moderate
Extending product lifespan	3.67	4.0	5	2.00	1.67	Moderate
Remanufacturing	3.33	3.5	3	2.50	1.44	Low
Increasing service intensity	2.83	3.0	2	2.00	1.03	Low
Redistributing	2.83	2.5	5	3.50	1.59	Low

Abbreviation: IQR = interquartile range.

The same logic applied to the willingness to share the data (5 = can be easily shared with partners, 1 = cannot be shared). The results were compiled, and the average score for each SCV-related data element was calculated. A statistical analysis was performed to check whether significant differences emerged in the perceptions of data accessibility versus the willingness to share data for any data element.

4 | Results

As explained in Section 3, authors identified 11 CE strategies and 16 critical data elements as a result of subsequent rounds of the Delphi method. Those elements, all deemed important by the experts, should be captured and shared within supply chains to effectively implement the CE strategies.

4.1 | Prioritizing CE Strategies

Based on the statistical analysis of the Likert scale scores shown in Table 3, three distinct clusters emerged from the data. Cluster 1 consisted of top-rated strategies related to reducing/eliminating waste, resource-efficient production, repairing, transport efficiency, and recycling, all of which the experts prioritized as being the most important for implementing CE strategies. Mean scores, ranging from 4.25 to 4.67, indicated strong expert agreement on criticality and importance. The mode, 5, further supported that conclusion by showing that the most frequent rating was the highest possible one. The low standard deviations, especially for reducing/eliminating waste and resource-efficient production ($SD < 0.80$), suggest strong agreement among experts about the high importance of those categories.

By contrast, Cluster 2 consisted of the CE strategies of refurbishing, modular product design, and extending product life, all of which were rated as being moderately important.

The mean values for those strategies, ranging from 3.67 to 3.75 with medians of 4, indicated a moderate level of importance, with higher variability suggesting context-dependent importance. The mode, 5, suggests that although the average importance was moderate, a significant number of experts nevertheless rated those items as being very important. The higher standard deviations indicated more variability in the responses, thereby suggesting relatively less consensus among experts that would require additional expert discussion and/or clarification.

Last, Cluster 3 consisted of the CE strategies of remanufacturing, increasing service intensity, and redistributing, all of which were rated as being of little importance. Lower mean values, ranging from 2.83 to 3.33, and medians less than 4 indicated that those CE strategies were generally considered to be less important. The modes, varying from 3 for remanufacturing, 2 for increasing service intensity, and 5 for redistributing, revealed variability in the most frequent ratings. The higher standard deviations for those categories also suggest more variability, whereas mixed distribution in the responses makes them less universally applicable. For redistributing, both the mean and median were less than 3, thereby indicating that experts rated the item as being less important. However, the mode of 5 suggests that whereas many experts rated the item as being less important, several of them rated it as being very important.

Using the interquartile range (IQR) as a measure of disagreement, the CE strategy of redistributing had the highest dispersion (3.50) of expert opinion observed in the study (see Table 3). The high IQR suggests a polarized opinion among the experts; although a majority considered the item to be less important, a significant minority found them to be very important. Such distribution indicates divided opinions, with a strong group of experts attaching high importance to the item. Such disagreements are common in Delphi studies and sometimes persist even after multiple rounds. Often stemming not from fundamental conceptual differences but from varying industry contexts, regulatory environments, and/or implementation-oriented priorities, they provide important contextual information that quantitative rounds alone cannot capture. Nevertheless, as mentioned, those disagreements and low degrees of consensus were highlighted during the webinars, and the experts were asked to provide their reflections, as discussed in the next section. Table 3 compiles the results related to the scoring of the CE strategies.

4.2 | Mapping Data Elements

The results from mapping the CE strategies with data elements, shown in Figure 1, revealed some clear hotspots and robust links among the CE strategies and their corresponding data elements. The results also showed strong correlations and consistency with the experts' categorization and ranking of the CE strategies.

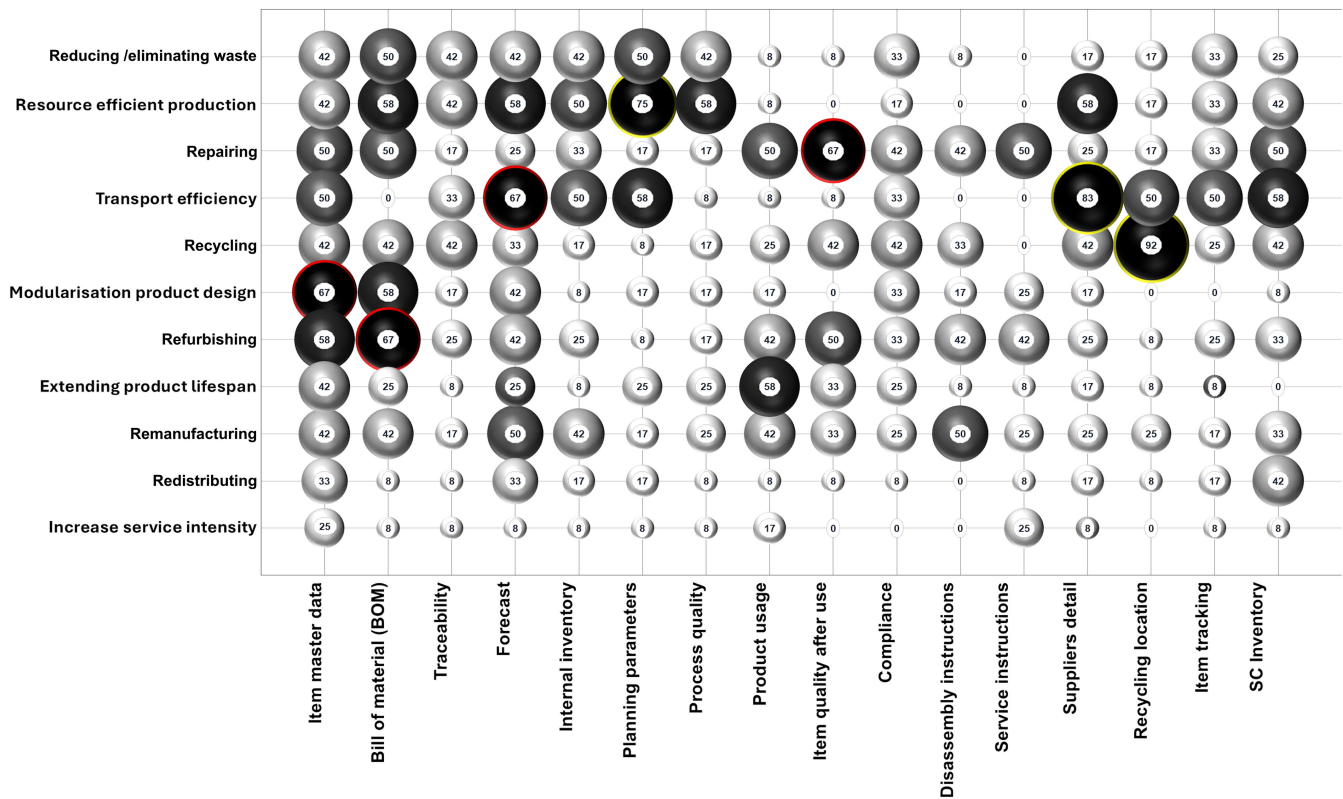


FIGURE 1 | Mapping of data elements to the circular economy (CE) strategies based on experts' responses. The size of the bubble at each intersection of the x-axis (i.e., data elements) and y-axis (i.e., CE strategies) indicates the importance of the data element to the corresponding CE strategy. Smaller bubbles signify lower values (i.e., fewer experts responded that the element corresponded to the CE strategy, and vice versa). Numbers within each bubble indicate the percentage of experts who suggested that the data element is required for the CE strategy.

The first group comprised data elements corresponding to item master data, bill of materials (BoM), and forecasting. Those data elements were selected by the largest number of experts and corresponded to most of the CE strategies, which together made them the most important data elements for implementing CE strategies, particularly for the highest-rated strategies such as repairing, resource-efficient production, reducing/eliminating waste, and remanufacturing.

The second group comprised data elements corresponding to traceability, internal inventory data, product usage, item quality after use, compliance, and SC inventory. Those data elements were selected by a moderate number of experts and corresponded to some of the CE strategies, particularly the highly rated recycling, transport efficiency, and extending the product lifespan. Those characteristics made them moderately important data elements for implementing CE strategies.

The third and final group comprised data elements corresponding to planning parameters, process quality, disassembly instructions, service instructions, suppliers' details, recycling location, and item tracking. The selection of those data elements was highly scattered, meaning that they were chosen by the fewest number of experts. However, there were exceptions in which those elements were selected by most of the experts, albeit only for specific CE strategies. Examples were planning parameters and process quality data for the strategy of resource-efficient production, suppliers' details for transport efficiency, and recycling location for recycling.

4.3 | Accessibility of Data Versus Willingness to Share Data

In Round 5, the experts assessed the importance and accessibility of the data elements identified in earlier rounds, along with businesses' willingness to share them. The 16 elements that received an importance ranking of 3 or more on a 5-point scale were retained for further analysis. Table 4 shows the ratings for accessibility and willingness to share, along with the results of a *t* test comparing the means.

Table 4 indicates that the level of accessibility of data elements varied considerably across the 16 data elements, from 4.67 (i.e., close to the maximum of 5.0) to 2.33 (i.e., lower than the midpoint of the scale, 2.5). Willingness to share data exhibited a similar range, from 4.44 to 2.44. Interestingly, seven data elements scored higher for accessibility than for willingness to share (i.e., the first six in Table 4, along with item quality after use), whereas eight elements (i.e., in the lower part of Table 4) showed the reverse relationship. The remaining element, compliance, had the same score, 4.22, for both accessibility and willingness to share.

Internal inventory data and supply chain inventory data exhibited a statistically significant difference. Mean accessibility to internal inventory data was twice as high as that of supply chain inventory data (i.e., 4.67 vs. 2.33), whereas the willingness to share such data remained low, at 3.33. The significant difference between accessibility and willingness to share for both elements suggests that firms have good access to their own inventory data but are reluctant to share them. Conversely, while accessing

TABLE 4 | Accessibility of data (from highest to lowest) versus willingness to share data, with mean values and *t* test results for statistically significant differences between mean values and with bold numbers indicating higher accessibility and willingness to share.

Data element	Accessibility	Willingness	<i>p</i>
Service instructions	4.67	4.44	0.085
Internal inventory	4.67	3.33	0.021*
Item master data	4.56	4.44	0.380
Planning parameters	4.56	4.00	0.089
Bill of materials	4.44	3.78	0.025*
Forecast	4.33	3.78	0.138
Compliance	4.22	4.22	0.500
Disassembly instructions	3.88	4.13	0.085
Traceability	3.67	4.00	0.098
Process quality	3.63	3.75	0.392
Product usage	3.44	3.78	0.141
Suppliers' details	3.33	3.67	0.282
Item quality after use	2.67	2.44	0.297
Item tracking	2.50	3.38	0.044*
Recycling location	2.44	3.11	0.085
Supply chain inventory	2.33	3.33	0.027*

*Statistically significant at the 0.05 level.

inventory data in the CSC (i.e., supply chain inventory) seems difficult, firms appeared more willing to share them, which could indicate that the firms recognize the need for all actors to contribute data to make the CSC work effectively.

Last, data regarding BoM formed a core internal dataset that firms can access but are reluctant to share. By contrast, data about item tracking showed the opposite pattern; accessibility was low, but firms were willing to share such information. That trend likely reflects the prevailing understanding among firms that extensive data sharing across multiple actors is required for well-functioning CSCs.

5 | Discussion

SCV plays a pivotal role in successfully implementing CE strategies. Effective information sharing facilitates collaboration among stakeholders within the value network and thereby allows identifying opportunities for creating, retaining, and

optimally using value. In this study, the authors aimed to understand the relevance and importance of different CE strategies from the perspective of experts by examining how they are working toward achieving SCV for circularity. As a result, they identified and mapped different CE strategies and data elements as well as their interrelationships, as discussed in the following subsections.

5.1 | Understanding CE From Experts' Perspectives

The results show that companies prioritize CE strategies and practices mostly related to forward supply chains and supported by their existing business models. For example, some of the highest-scoring strategies (see Table 3), including reducing/eliminating waste, resource-efficient production, and transport efficiency, all focused on reducing the use of resources in forward supply chains. Those findings align with the results of Morsetto (2020), who highlighted that those strategies favor all other CE strategies and are essential to making the system truly circular. As such, those resource-reducing strategies should be implemented before resource-circulating strategies.

CEs primarily aim at extracting maximum value by keeping materials and value within the system for as long as possible while minimizing waste and environmental impact. The Ellen MacArthur Foundation has also stressed that CE strategies are designed to reduce and/or eliminate waste and pollution from the start and endorse regenerative systems that use resources efficiently. Likewise, the scientific literature (Kirchherr et al. 2023; Martin et al. 2024) stresses waste reduction, transport efficiency, and resource-efficient production as core principles of CEs because preventing waste at its source and efficiently using resources decreases the overall demand for virgin raw materials, which mitigates environmental degradation.

Furthermore, as discussed in the focus group webinars in Round 4, most industries have adopted a reactive approach under the assumption that waste will inevitably be generated. Consequently, they invest heavily in waste disposal and management. However, a more forward-thinking strategy would involve preventing waste generation from the outset. By redesigning and/or modifying traditional processes that produce waste, companies could significantly reduce or even eliminate waste. Such a proactive approach could prove to be far more effective in the long term. While reflecting on the summarized findings from the first three Delphi rounds, the experts commented, "We completely agree with the results," "We currently focus on redistribution and reducing waste," and "Reducing and eliminating waste is low-hanging fruit for us." The experts perceived that they could achieve more in terms of sustainability goals by first focusing on forward flows. One expert also highlighted the role of regulations and specific requirements in the final products that hinder reverse flows:

I think that the challenge for our product is a highly regulated environment. It's not so easy to bring products back from the market and do something again because we don't know where they've been,

what's happened to them, or how they've been used, which impacts the quality and material requirement regulations. Even we aren't sure about the exact composition of the recycled product.

Recent government regulations and consumer demands prioritize sustainability in production and the supply chain. In particular, policies and directives on batteries (2018) and electronics waste management (2012) encouraging circularity stress the elimination of waste and the responsible use of resources as mandatory elements of compliance to reduce environmental impact and achieve UN sustainability goals. According to one of the experts, "The practical and economically viable implementation and scaling of CE strategies downstream in the supply chain requires first minimizing waste and optimizing resource use." The EU's Right to Repair Directive (EU) 2024/1799 (Yakimova 2024) emphasizes and mandates the CE strategy of repairing for industries because it empowers consumers by legally mandating repairability, granting access to spare parts, providing transparent repair-oriented information, and preventing barriers to repair.

Literature on transport efficiency also highlights and supports this study's findings. For example, Ge et al. (2024) have highlighted that approximately 14% of total emissions in supply chains can be attributed to transportation. Thus, improving transport efficiency through route optimization, load consolidation, and low-emission vehicles can directly reduce fuel consumption and emissions, thereby leading to significant environmental benefits. An effective transport system is essential for reverse logistics operations (Ullah 2023). One of the experts highlighted, "Considering recent experiences from the Suez Canal, container shortages, and the [COVID-19] pandemic, effective CE strategies relate to transportation, regionalized logistics, and transport networks and shared transportation resources while reducing the dependence on global freight routes that are vulnerable to disruptions."

Regarding moderately important CE strategies such as modular product design, refurbishing, and extending product life, one expert explained why modular product design was not rated as highly important by citing an example of industrial doors: If we dismantle a door, can I dismantle it to the extent that reverse logistics can be efficient? But what will be the consequence for workshop technicians? They will have to do more work. So, one question is logistics cost versus product design. Similarly, as highlighted in the literature (Machado and Morioka 2021; Reike et al. 2018), CE strategies such as modular product design and refurbishing require transport efficiency for robust reverse logistics, inventory management, and quality control systems, which can be costly and complex to establish. Modular design can require changes in product design and substantial investments in new production systems (Machado and Morioka 2021), which limit immediate impacts compared with simpler CE strategies such as waste reduction. Moreover, whereas strategies of repairing are supported by legislative frameworks, refurbishment remains fragmented in practice due to a low willingness to pay among consumers and difficulties in guaranteeing quality that can impact the reputation of brands (Reike et al. 2018). Regarding the CE strategy

of extending product life, research by Jensen et al. (2021) has identified technological and symbolic obsolescence as social factors that prevent extending product life cycles despite their technical feasibility. Thus, the strategy conflicts with established patterns of consumption that prioritize novelty and frequent replacement.

While discussing the third cluster of CE strategies (i.e., remanufacturing, redistributing, and increasing service intensity), which the experts rated as being of low importance, most experts agreed with the rating, though some had different opinions. Stressing the CE strategy of remanufacturing, an expert mentioned:

Our products have a long lifespan—more than 10 years—which makes it challenging to track their entire life cycle. Initially, we sell our products to the first customer, and subsequently, they pass through multiple owners—second, third, fourth, and so on. Often, products start their life in one part of the world and then find a second life in another, which makes it even more difficult to track and acquire cores for remanufacturing. Thus, remanufacturing becomes challenging.

Other experts expressed that the strategy of increasing service intensity requires a business model to shift toward servitization, which itself requires new partners in a new ecosystem, new capabilities, and, most importantly, a shift in the mindset of customers. The strategy of redistributing, by contrast, requires the optimized sharing, reassignment, and relocation of resources, which is complex and necessitates a highly interconnected transportation network with an approach to balance cost and benefits (Björklund et al. 2025). For some of the experts, especially ones representing chemical, fasteners, and one-time-use products, particularly medical and healthcare products, CE strategies such as remanufacturing, redistributing, and increasing service intensity are not applicable, which further explains the low rating and difference in opinion. In

line with recent studies on the implementation of CSCs (e.g., Amir et al. 2023), the findings underscore the importance of adopting a systemic approach, which involves designing business models, products, and supply chains to effectively close the loop.

5.2 | Critical Data Elements of SCV

5.2.1 | Accessibility Versus Willingness to Share

The findings offer valuable insights into the accessibility of SCV-related data and the willingness of supply chain executives to share said data with other supply chain partners. The difference between accessibility and willingness to share data, shown in Table 4, was further analyzed in graphical form, shown in the scatterplot in Figure 2.

A review of the positions of the 16 data elements in Figure 2 suggests that they fall into three groups, divided based on their accessibility scores. Group 1 consists of data elements that are core to the firm and intended for internal operations planning. Those elements do not primarily reflect a circularity perspective but focus on supporting the forward supply chain. Firms have high accessibility to those data elements due to their internal nature but show less willingness to share them, as is particularly evident for BoM-related and internal inventory data, willingness scores for which were significantly lower than accessibility scores. A similar trend emerged in the mapping of data elements with CE strategies, as shown in Figure 1, in which a high percentage of the experts perceived BoM-related and inventory data crucial for the highly important CE strategies of reducing/eliminating waste, resource-efficient production, repairing, and transport efficiency. Previous studies (Jang et al. 2024; Ketzenberg et al. 2023) have also highlighted that companies view BoM-related and inventory data as intellectual property that can enable firms to reduce friction in contracting and thereby provide a competitive advantage (Jang et al. 2024; Ketzenberg et al. 2023).

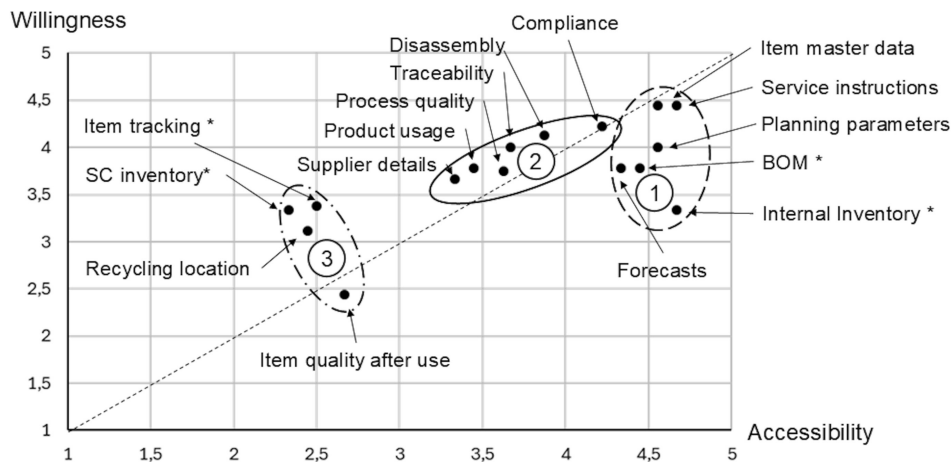


FIGURE 2 | Accessibility of data versus willingness to share data; the dotted line along the diagonal indicates situations in which the two aspects received equal scores, such that willingness is greater than accessibility above the line and less than it below the line. *Note:* *Significant difference between accessibility and willingness. BoM = bill of materials, SC = supply chain.

By contrast, Group 2 includes data elements related to principles of CE. For those elements, both accessibility and willingness to share are relatively high, which suggests that when firms have access to those data elements, they are also inclined to share them with other actors involved in the CSC. Those data include compliance data, which, when shared with supply chain actors, ensures regulatory adherence, risk management, and sustainability in supply chains (Bjerre and Parbo 2021) and was mapped as essential for most of the CE strategies by the experts. Next on the list are traceability data, which are crucial for tracking the footprint of products throughout supply chains (Carlsson and Nevzorova 2025). Some experts, especially those representing highly regulated supply chains or cold supply chains, deemed traceability data to be crucial and essential to share with other actors. Similarly, regulations mandating DPPs require companies to share those data (Jensen et al. 2023), whereas data related to disassembly instructions and product usage were considered by the experts to be enablers of CE strategies such as repairing, refurbishing, and remanufacturing. These data ensure regulatory compliance and supply chain optimization and should be shared because they represent technically necessary information for product end-of-life management, as well as provide mutual benefits with minimal competitive risk (Jensen et al. 2021). Data about suppliers' details are crucial for transport efficiency, resource efficiency, and the effective recycling and processing of quality data in order to reduce waste and ensure efficient resource use.

Last, Group 3 comprises four data elements with low scores for accessibility and willingness to share. Those elements may be difficult to capture or may not have been prioritized by firms. For example, accessibility may be an antecedent for willingness to share, which explains the low scores for the latter, although access to those data elements is likely necessary for firms to be willing to share the corresponding data. In particular, data related to item quality after use represent crucial input for the strategies of repairing, refurbishing, and remanufacturing. Nevertheless, due to high uncertainty and randomness in product usage, along with inadequate infrastructure to track product quality, customers' unwillingness, and technical limitations, the availability of such data is limited. Data related to recycling location, item tracking, and supply chain inventory, meanwhile, are deemed to be important for CE strategies such as repairing, transport efficiency, and recycling but are mostly unavailable due to inadequate infrastructure.

Despite prevailing challenges, all those data elements are essential for the effective implementation of CSCs. Comparing Group 2 and 3, the results suggest that data representing Group 2 are more readily available to firms in CSCs, who are also willing to share them. By contrast, data representing Group 3 lag in both accessibility and willingness. The statistically significant difference between accessibility and willingness for SC inventory and item tracking indicates that those two data elements are perceived as being difficult to capture. However, firms also seem to recognize their importance for sharing within CSCs. If firms can capture all 16 data elements and are willing to share them, then the level of SCV will improve, and circularity in the supply chain will ultimately be enhanced.

5.3 | Mapping Data Elements to Circular Resource Flows

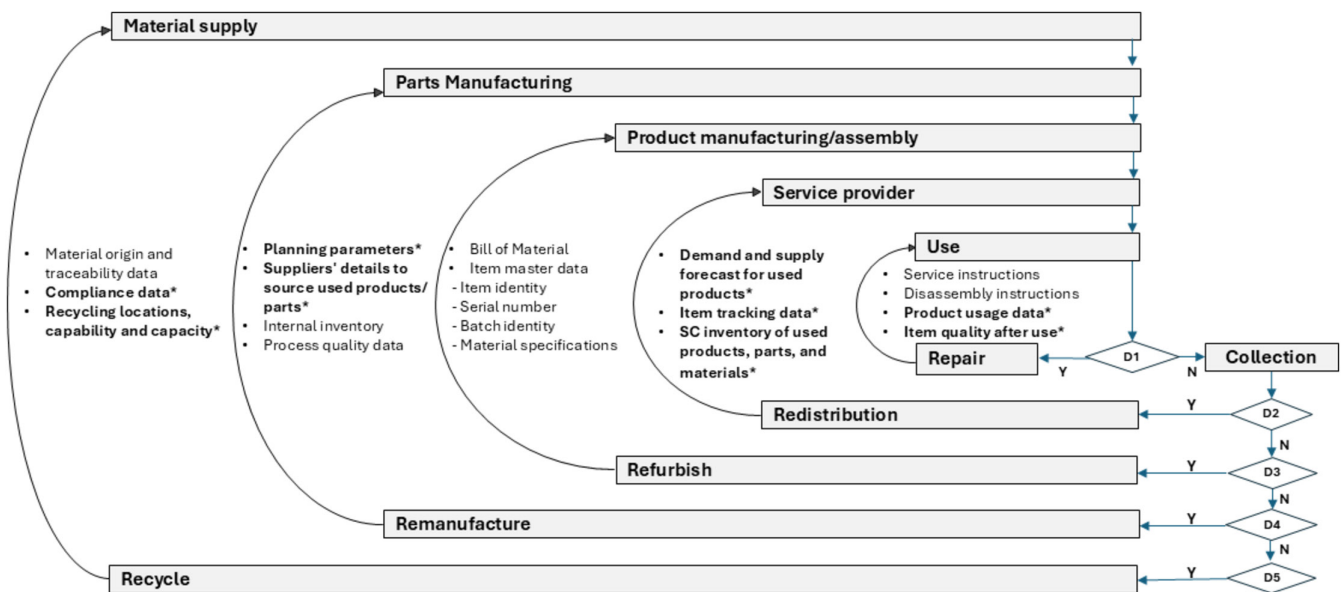
Based on our literature review and Delphi study, the data elements can be mapped to different circular resource flows. Of the identified CE strategies, five involve circular flows of resources, as previously pointed out by Potting et al. (2017) and Morsetto (2020): repairing, redistributing, refurbishing, remanufacturing, and recycling. Those circular resource flows help to extend the use and lifespan of products, components, and materials and contribute to circularity aligned with the inertia principle, as proposed by Stahel (2010, 195) and the value hill framework proposed by Achterberg et al. (2016). The inertia principle advocates minimal intervention with the advice of “do not repair what is not broken, do not remanufacture something that can be repaired, and do not recycle a product that can be remanufactured. Replace or treat only the smallest possible part in order to maintain the existing economic value” (Stahel 2010). Similarly, the value hill framework emphasizes the importance of “keeping products for as long as possible at their highest value on the Value Hill.” Considering that value-preserving prioritization logic, the identified data elements are further attributed to forward and reverse flows. As illustrated in Figure 3, sharing specific data elements from both flows is necessary to maintain visibility and support the circular flow of resources under different CE strategies.

To implement a strategy of repairing, critical data elements from the forward flow include service and maintenance instructions, as well as disassembly guidelines generated during the manufacturing or assembly stages. From the reverse flow, essential data consist of product usage and condition information. The findings indicate that item quality after use is less accessible and that companies are often reluctant to share said information with partners (see Figure 2). Taken together, those data elements are crucial for enabling efficient and effective repair operations, as also highlighted by Jensen et al. (2023).

For the redistributing strategy, additional data elements required from the reverse flow include demand forecasts for used products and information on the locations and inventory levels of used products. As pointed out by Wilson and Goffnett (2022), those data elements help to identify market needs for used products and improve logistics efficiency by allowing service providers to source and distribute used products more effectively.

Implementing a refurbishing strategy requires the exchange of data from both the forward and reverse flows. Most of the data elements identified for repairing and redistributing strategies are also essential for refurbishing, whereas key forward-flow data elements include the BoM-related and item master data, such as product identity, serial number, batch number, and material specifications. Those data elements have also been identified by Jensen et al. (2023) as priorities for selecting and employing value-retention strategies at the product level.

For the strategy of remanufacturing, additional reverse-flow data on planning parameters are essential for effectively sourcing and transporting products for remanufacturing in a coordinated manner. In addition, data about process quality and



D1: Can it be repaired?, D2: Can it be redistributed?, D3: Can it be refurbished?, D4: Can it be remanufactured?, D5: Can it be recycled?, Y: Yes, N: No

FIGURE 3 | Onion model of data and information layering for circular resource flows. Note: *Reverse-flow data elements. D = decision point, SC = supply chain.

internal inventory are essential for optimizing resource utilization and minimizing waste during both manufacturing and remanufacturing operations. As noted by Acerbi et al. (2021), the effective implementation of remanufacturing relies on both product and process data elements.

Last, for the recycling strategy, additional data on material composition, origin and traceability, and regulatory compliance, along with the capacity and location of recyclers, are necessary for both material suppliers and manufacturers. Among them, material composition is considered priority data for implementing recycling strategy, as also observed by Jensen et al. (2023).

The findings imply that as companies move toward outer resource flows—for example, refurbishment, remanufacturing, and recycling—each successive flow requires an additional layer of data and information to support its implementation. That dynamic can be visualized as the layers of an onion (see Figure 3), the innermost of which represents the data required for inner loops (e.g., repairing and redistributing), and each outer layer adds progressively more detailed, process-specific information needed for increasingly complex flows. For example, the inner layers include service instructions and disassembly guidelines, which are necessary for repair. Moving outward, refurbishing and remanufacturing require additional layers of data, including data about the BoM, material composition, and process quality. The outermost layer, recycling, depends on even more granular information, including material origin and traceability, as well as recyclability characteristics. Such a layered accumulation and integration of forward- and reverse-flow data enhances visibility across the life cycle of products and support informed, data-driven decision-making that enables the effective implementation of CE strategies.

The data elements mapped across the forward and reverse flows come in different forms: static, dynamic, and cumulative (see Appendix, Table A2). Static data elements remain constant until they are replaced by more relevant information; for example, service instructions are static until updated. Dynamic data elements capture continuously changing information and need regular updates; a typical example is the location of items. Last, cumulative data elements record information that accumulates over time—for instance, product usage data (e.g., how long or how many times a product has been used).

The nature of the data captured through the identified data elements helps to explain why certain types of data are particularly important at specific points in the forward and reverse flows. Static data are created at their earliest position in the value stream and preserved as items move through different loops. By contrast, dynamic and cumulative data are continuously updated as items flow through the loops, which enhances visibility and enables better circularity in the supply chain.

The required data elements for circular resource flows consequently represent a mix of specific data elements. They could be understood in relation to the volume, variety, and velocity dimensions of the literature representing big data (e.g., Hazen et al. 2014; Lamba and Singh 2017). *Volume* describes the amount of data that increases when moving toward the outer resource flows. Although the literature refers to a variety of data being structured or unstructured, have mainly identified structured data but recognize how the data on circularity vary in the dynamic and static dimensions. Next, *velocity* refers to the efficiency and speed of collecting and processing data, which, for example, results from the accessibility and willingness to share data in the supply chain and from the variety of the data. Because the data on circularity clearly constitute big data, especially in the outer layers of resource flows, it would be

interesting for future research to study their implications on information sharing and use (e.g., Bellini et al. 2024; Jonsson and Myreliid 2016) of the big data characteristics at different layers of resource flows.

6 | Conclusion and Directions for Future Studies

6.1 | Conclusions

Although the need for information sharing to improve supply chain collaboration and SCV is firmly established in the literature, it remains challenging to achieve it in practice. Moreover, enhancing SCV with a primary focus on better material circularity only adds a layer of complexity. The transition toward circular production requires a comprehensive understanding of the intersection between SCV and CE strategies. The findings suggest that a way forward is to understand data-related needs at different stages of the supply chain to fully leverage circularity-oriented strategies. The strategies and practices identified in this study provide insights into how information sharing and visibility in supply chains can improve the circularity of materials and parts. A key observation is that carefully considering the type and importance of different data elements is crucial for ensuring that complementary actions toward CE are effective.

6.2 | Managerial Implications

This study offers valuable insights for supply chain and sustainability managers to establish connections with data elements that need to be recorded and shared within supply chains to effectively implement CE strategies. First, the results indicate that managers should treat SCV as a strategic capability that adds value when it targets information that enables resource recovery—for example, material traceability and reverse logistics flows. Prioritizing such data ensures that visibility contributes directly to circular value creation. Second, the identified key strategies and practices aligned with CE principles, along with critical information sets, serve as pivotal guideposts for discussion. Those insights can help managers to plan and implement material circularity through SCV tailored to their specific situations. Third, this study provides a foundation for collaborative discussions on which data elements supply chain actors should be prepared to make visible to a certain extent. Cross-functional collaboration between sustainability, operations, and procurement teams is essential to determine which information is truly useful and actionable for specific circular goals. Such transparency is necessary for effectively implementing CE strategies on a broader scale. Fourth, at the operational level, the study identifies an imbalance between *data accessibility* and *willingness to share*. Although most firms already possess relevant internal data, mechanisms for sharing such data externally remain underdeveloped. Shared dashboards, exception alerts, and common performance metrics can translate accessible data into decisions that benefit multiple actors. As emphasized by Kalaiarasan et al. (2022), relational governance and joint standards are crucial to sustain data accuracy and timeliness across tiers. Fifth, SCV for circularity depends on trust, reciprocity, and shared incentives to exchange information about products, materials, and environmental performance. Managers can build relational

readiness through initiatives that clarify the value and limits of data exchange. Those findings echo the importance–feasibility tension noted by Kembro et al. (2025), which holds that visibility is most valuable but also most difficult to achieve in complex, uncertain contexts. Thus, a phased governance approach combining contractual clarity with relational flexibility can help to scale visibility across circular networks.

6.3 | Implications for Research and Directions for Future Studies

The lack of effective information sharing can hinder the adoption of circular strategies in supply chain management. Research on CE strategies has shown that CE strategies are important depending on the value that they make retainable in a given product. Although information sharing and SCV are broadly regarded as being important for CE, empirical evidence on which data elements are important to which strategy is often lacking. This study has highlighted a complementary perspective to existing theory by mapping the importance of SCV-related data elements to CE strategies. Indeed, not understanding such relationships or low prioritization of the relevant data elements could provide obstacles to the effective adoption and achievement of CSCs.

Having those key observations opens further avenues for research. For example, large-scale cross-sectional studies could help to scrutinize and validate the findings. It would also be of interest to identify how and when supply chain actors change their opinions about the importance of certain CE elements and the relative influence of data elements on those strategies. Future research could additionally explore how current shortcomings and gaps toward realizing CSCs can be addressed and what enabling scenarios might exist, including the emergence of new actors that facilitate the creation of tandem business models or alter traditional business models altogether, including the role of technological advances. One promising direction is investigating how regulatory environments and policies, including waste management laws and extended producer responsibility, influence data-sharing practices and the adoption of CSCs. On top of that, examining behavioral factors, including organizational culture and trust, could shed light on how those elements affect the willingness to share SCV-related data. It would also be interesting to further analyze how the big data characteristics of circular data elements affect information sharing and utilization. Last, because this study focused on data and information that provide visibility in circular resource flows, future research should consider the need for and accessibility of data and information to track, monitor, and manage the financial flows in CSCs and their impact on circularity and sustainability.

Some limitations of the findings may impact or influence their interpretation, and some of them are inherent to the use of the Delphi method. In particular, although authors tried to overcome issues related to the experiences, conformity bias associated with consensus-building, and the geographical focus of the panel, those limitations cannot be fully eliminated. As a countermeasure, authors deliberately selected experts from a wide range of industries and from organizations with global operations in order to capture a broader, international perspective.

Nevertheless, the approach does not fully mitigate bias, for experts may still reflect the regulatory and institutional contexts of their headquarters, regardless of the global nature of their companies. Authors also acknowledge that they did not include financial, behavioral, or policy-related aspects of data sharing—for instance, cost implications, trust, and regulatory influence—which could have resulted in some additional insights. Finally, this study was subject to a fundamental epistemological limitation in that it captured subjective managerial perceptions instead of objective operational reality. Moreover, the study represents only a static snapshot of expert consensus at a particular point in time and may evolve as regulatory frameworks and industry practices continue to change.

Author Contributions

Tarun Kumar Agrawal: conceptualization, methodology, data curation, formal analysis, writing – original draft, writing – review and editing. **Ravi Kalaiarasan:** conceptualization, methodology, formal analysis, writing – original draft, writing – review and editing. **Sayed Shoaib-ul-Hasan:** conceptualization, formal analysis, writing – original draft, writing – review and editing. **Seyoum Eshetu Birkie:** conceptualization, formal analysis, writing – original draft, writing – review and editing. **Sandeep Jagtap:** conceptualization, writing – original draft, writing – review and editing. **Jan Olhager:** conceptualization, methodology, formal analysis, writing – original draft, writing – review and editing. **Magnus Wiktorsson:** conceptualization, formal analysis, writing – original draft, writing – review and editing. **Patrik Jonsson:** conceptualization, writing – original draft, writing – review and editing. All authors have read and approved the final version of the manuscript.

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Conflicts of Interest

The authors declare no conflicts of interest.

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Appendix

TABLE A1 | Descriptives of experts involved in the Delphi study.

Code	Industry subsector	Position	Experience (years)
C1	Energy smart systems	Digital supply chain office	20+
C2	Telecom	Circularity lead	10+
C3	Outdoor power products	Operations strategy and development director	27+
C4	Furniture	Business development manager	25+
C5	Packaging solutions	Global SC manager	15+
C6	Chemical products	VP operations and supply chain	30+
C7	Industrial doors	Director, material management, and logistics	30+
C8	Automotive	Project manager	18+
C9	Heating solutions	Supply chain manager	10+
C10	Automotive	Sustainability manager, VPS, and quality manager	15+
C11	Machinery	Head of global planning	19+
C12	Medical and healthcare	Global logistics PMO director	26+
C13	Automotive	Chief executive officer	25+
C14	Electronics	Logistics manager	15+
C15	Automotive	Director, SCM strategy	25
C16	Automotive components	Head of operations	20
C17	Fasteners	Sustainability manager	15
C18	Home appliances	VP logistics	20+
C19	Metalworking	Global environmental, health, and safety manager	10+
C20	Furniture	Transformation manager	15+
C21	Aerospace	Supply chain manager	15+
C22	Forest and Garden	Senior director, SC strategy	25

TABLE A2 | Data element descriptions, example quotes, and nature of data.

Data element	Description	Examples from panel participants	Nature of data ^a
BoM	Bill of material (BoM), product structure	<p>“Bill of Material can make it easier to know the content of a recycled product” (C7)</p> <p>“Information about product unique components can help calculating future scrap liability risks from business decisions” (C1)</p> <p>“Information on the material the product is made of that can be automatically read in the recycling process to separate ‘material’ streams in more fractions than today to maintain a higher value of the ‘waste’ and thereby produce higher value recycled material than today” (C17)</p> <p>“Product content information can help to take care of products after life cycle” (C16)</p>	Static + cumulative
Compliance	Standardization and regulatory requirement	<p>“Legislation can force producing companies to work with circularity” (C4)</p> <p>“Better country specific legislations for circular flows (today some ‘wastes’ are not allowed to send cross borders) can make it possible to transport specific material cross borders and avoid small handling units in every country that the waste occurs in” (C11)</p> <p>“Compliance with standards applicable to recycling” (C4)</p>	Static
Disassembly	Disassembly instructions	<p>“Information to disassemble in an easy way without damaging the products makes any kind of reuse or remanufacturing easier” (C3)</p>	Static
Forecast	Demand and supply forecast for used products	<p>“Customer demand forecast and forecast changes to match new demand of R-products with return flow from customers” (C1)</p> <p>“Get more visibility of from-to flows of products on global level to enable more consolidation of shipments” (C13)</p> <p>“Visibility of customer products that can be returned and recycled” (C11)</p> <p>“Information about potential volumes of used parts” (C15)</p>	Dynamic
Internal inventory	Internal inventory data	<p>“Information about excess inventory in all stock locations to prevent and minimize internal waste” (C2)</p>	Dynamic
Item master data	Item related data (item number, item quality, material specification, etc.)	<p>“Information about serial number makes it easier to know age of the components to be refurbished” (C7)</p> <p>“Information about material specification can help design a closer loop. For example, remelt alloy instead of refining” (C3)</p> <p>“Material description helps identify material that can be recycled, or with supply constraints (availability, price ...)” (C15)</p> <p>“Information about product content/material declarations from suppliers can make it easier to find recycling/reuse options for the products” (C11)</p> <p>“Unique identity supports safety and effectiveness in all processes: Disassembly, consolidation (for transport), choice of packaging, sorting for recycling, choice of recycling process” (C13)</p> <p>“Information on the material the product is made of that can be automatically read in the recycling process to separate ‘material’ streams in more fractions than today to maintain a higher value of the ‘waste’ and thereby produce higher value recycled material than today” (C17)</p> <p>“Product content information can help to take care of products after life cycle” (C16)</p> <p>“Information about material specification per component can make it possible to recast, remake or to send to a process step at a supplier which is best suitable” (C3)</p> <p>“Identifier of product down to batch level can help with compliance with standards applicable to recycling” (C4)</p>	Cumulative

(Continues)

TABLE A2 | (Continued)

Data element	Description	Examples from panel participants	Nature of data ^a
Item quality after use	Item quality after use	<p>“Knowing what, how much, where and at what quality and thus being able to sort it for re-use, re-new or recycle will ensure that the volume ends up in the right flow and process” (C4)</p> <p>“Knowing component quality to improve supplier base and future product designs” (C1)</p>	Cumulative
Item tracking	Item real-time tracking data (forward and reverse supply chains)	<p>“Real-time goods in transit from return flows for more precise demand and supply planning of R-products to customer” (C1)</p> <p>“Product tracking after sell to knowing when the appliance is disposed and where and how, that could also help to understand if any refurbishment—reconditioning policy could make sense” (C18)</p> <p>“Get more visibility of from-to flows of products on global level to enable more consolidation of shipments” (C12)</p>	Dynamic
Planning parameters	Planning parameters considering return flow of materials	<p>“Planning potential and resource management, creating visibility where material and awareness of potential of used material” (C15)</p> <p>“Planning to secure resources (volumes, manpower, etc. ...)” (C15)</p> <p>“Information about buffers and inventory to avoid unbalanced KPIs that drive waste” (C1)</p> <p>“Any information that will facilitate highly efficient transports of goods from end user to refurbishment would be of value” (C17)</p> <p>“Get more visibility of from-to flows of products on global level to enable more consolidation of shipments” (C12)</p> <p>“Information to use inbound/outbound more efficiently and avoid unnecessary KM on the road. As is today supplier being responsible for inbound and customer for outbound without any connections to one or another” (C16)</p>	Dynamic
Process quality	Process quality data	<p>“Information collected during the various stages of a production or service process to ensure that the process meets predefined quality standards” (C22)</p>	Dynamic
Product usage	Product usage data	<p>“Information about how customers interact with a product which provides insights into user behavior, such as when and how often they use the product” (C21)</p>	Cumulative
Recycling location	Location, capability and capacity of recyclers	<p>“Locations of recyclers to optimizing recycling and minimize the CO₂ emissions from transportation” (C1)</p> <p>“Clear information from recycling locations which material they can recycle, and volume needed to more easily connect to the optimal partner for our recycling” (C14)</p> <p>“We know that the return logistics and transport have a high cost. Either we must establish local/regional recycling processes or secure that consolidation of collection and transport” (C13)</p>	Static
Service	Service, maintenance and upgrade instructions and plans	<p>“Information about service contracts, planned repair dates, planned swaps and HW/SW upgrades can help to ensure supply to customer on time” (C1)</p>	Static
Supplier details	Location, capabilities and capacities of suppliers	<p>“Information about location where to find used parts” (C15)</p> <p>“Information about process steps, material flows and volumes from local suppliers for more efficient collection and transports of the materials in scope for reuse” (C11)</p>	Static
Supply chain inventory	Inventory of used products, parts, and materials in the circular supply chain	<p>“Having an overview on what can be returned from a customer could enable better logistic planning and increase fill rate in the reverse logistics flow” (C11)</p>	Dynamic
Traceability	Material origin and traceability data	<p>“More info from 3- to 4-tier suppliers on origin of materials to increase use of recycled material” (C12)</p>	Cumulative

(Continues)

TABLE A2 | (Continued)

Data element	Description	Examples from panel participants	Nature of data ^a
Data elements that were excluded after round 3			
Batch identity	Batch number	“Identifier of product down to batch level can help with compliance with standards applicable to recycling” (C4)	Static
Carbon footprint	CO ₂ emission impact	“Easier to understand product’s impact on CO ₂ emission” (C7) “If we also could add the parameter Product Performance in relation to CO ₂ footprint for each product it would support a more efficient use of input materials” (C1) “Embodied carbon for product and components to drive behavioral change in internal waste management” (C2)	Cumulative
Installed base of product	Number of products that are currently in use by customers	“Having an overview on what can be returned from a customer could enable better logistic planning and increase fill rate in the reverse logistics flow” (C11)	Dynamic
Packaging	Packaging instructions for better care of circular products	“Packaging instructions for better care of products in the return flow so they are not damaged” (C15)	Static
Reasons for scrapping	Reasons for scrapping to reduce waste in forward flows	“Information about reasons for scrapping to prevent internal waste” (C2)	Static
Recyclability	Item recyclability and recycling instructions	“All packaging but even parts have visible marking showing how to be recycled. Packagings and parts could more easily be sorted by anybody. Higher sorting quality and bigger volume per type of material” (C14) “Information about parts recyclability to know if it can be recycled, refurbished, repaired” (C15)	Dynamic
Scrap threshold	Information about scrap threshold for waste reduction in forward flows	“Information about scrap targets to avoid unbalanced KPIs that drive opposing business incentives” (C2)	Dynamic

^aNature of data: “Static” data are kept the same until a major change is made to the item or the item is taken out of the value chain; “Dynamic” data change with changes in the material flows; “Cumulative” data capture and record incremental changes over time, accumulating information about both data and material flows.