Received 27 June 2025
Revised 13 November 2025
17 March 2026
14 April 2026
Accepted 16 April 2026

Smart packaging's role in enhancing logistics capabilities for a circular economy: a systematic literature review

Promporn Wangwacharakul
Department of Management and Engineering, Linkoping University, Linkoping, Sweden
Justina Karpavice
Department of Business Development and Technology, Aarhus University, Herning, Denmark
Malgorzata Fialkowska-Filipek
Department of Management Systems and Organizational Development, Wrocław University of Science and Technology, Wrocław, Poland, and
Yash Chawla
Department of Operations Research and Business Intelligence, Wrocław University of Science and Technology, Wrocław, Poland

Abstract

Purpose – This study systematically explores the pathways through which smart packaging (SP) enhances logistics capabilities (LCs) to simultaneously address two key challenges for the circular economy (CE) – physical value and information loss. While the link between SP and circularity is recognised, the specific pathways through which item-level data reconfigures LCs and leads to circular outcomes remain underexplored. This paper clarifies these connections, detailing how and why SP serves as a foundational enabler for the strategic transition from reactive recovery to proactive circular supply chains.

Design/methodology/approach – Following a theory-informed systematic literature review (SLR), 59 articles were analysed using axial coding and multi-layered framework synthesis. The research utilises packaging functionalities (PFs) and LCs as micro-level and macro-level units of analysis, respectively, while adopting the R-imperative framework as a strategic lens to map circular outcomes.

Findings – The study identifies four thematic pathways: (1) proactive logistics management and dynamic optimisation, (2) autonomous and scalable reverse flows, (3) systemic trust and quality of material streams, and (4) collaborative value co-creation. The findings demonstrate that SP-enhanced LCs address the challenges of achieving circularity by mitigating physical value loss through functional preservation and information loss through item-level visibility. Information-management capabilities are the foundational antecedents allowing supply-management, demand-management, and coordination capabilities to mitigate the information asymmetry inherent in closed-loop systems.

Originality/value – This research develops a novel multi-layered conceptual framework explaining the "how" and "why" behind SP-enabled higher-order circularity. It identifies the theoretical boundaries of logistics-led interventions, highlighting the limits of item-level intelligence in supporting design-led strategies like repair and refurbish.

Keywords Reverse logistics, Dynamic capabilities, Active packaging, Intelligent packaging, Data-driven logistics, Packaging functionalities, R-imperatives, R-strategies

Paper type Literature review

Funding: This work was supported by Svenska Forskningsrådet Formas (award id: 2021-02445) and National Science Centre (NCN), Poland (award id: 2022/47/D/HS4/03444).

International Journal of Physical
Distribution & Logistics Management
Vol. 56 No. 5, 2026
pp. 520-543
Emerald Publishing Limited
e-ISSN: 1758-664X
p-ISSN: 0960-0035
DOI 10.1108/IJPDLM-06-2025-0302

1. Introduction

Digitalisation has evolved packaging from a passive container to a strategic asset for supply chain (SC) efficiency (Perotti *et al.*, 2025). This shift is enabled by SP, which integrates intelligent, active, and connected technologies into conventional packaging, such as radio-frequency identification (RFID) tags, QR codes, and sensors (Endara *et al.*, 2023; Lydekaityte and Tambo, 2020). By enhancing traceability and enabling real-time data exchange (Chen *et al.*, 2020), SP represents a technological advancement that redefines the business model and creates value in logistics and supply chain management (LSCM). As sustainability becomes a standard requirement, the CE has moved to the forefront, aiming to reduce waste and resource consumption by keeping products and materials in use for as long as possible (Kirchherr *et al.*, 2017).

Despite the direct influence of packaging and logistics operations on a firm's efficiency and effectiveness (Dev *et al.*, 2021; Gatenholm *et al.*, 2021), the specific processes through which SP reconfigures logistics activities to address challenges of circularity remain fragmented and underexplored. Within the CE transition, LCs are essential competencies used to reconfigure resources and gain competitive advantage in response to circular challenges (Sandberg and Abrahamsson, 2011). Integrated LCs are a dominant influence on a firm's ability to build resilience and manage the inherent complexity of circular systems (Mandal *et al.*, 2017). Consequently, SP serves as a potential enabler for enhancing these LCs and supporting the CE transition by facilitating timely access to information and coordination (Beske, 2012).

While the literature recognises SP's contribution to circularity, existing reviews often lack a detailed understanding of the "how" and "why" behind this connection (Chen *et al.*, 2020; Palazzo *et al.*, 2023). The value of technology is only realised when a clear link to the capabilities it enhances is established (Riggs *et al.*, 2023); yet research on SP's role in CE often remains superficial (Abekoon *et al.*, 2024; Yang *et al.*, 2024). Notably, a strong growth trend in publications over the last five years has provided the critical mass of evidence required for this SLR. To fill this gap, this study provides a theory-informed SLR that synthesises fragmented knowledge into a rigorous analytical foundation (Durach *et al.*, 2017; Kembro *et al.*, 2025).

We conceptualise the CE transition as being fundamentally rooted in the simultaneous mitigation of physical resource loss and information asymmetry across the SC. While design-led strategies prioritise waste prevention, the operational core of circularity – recovering and extending product lifecycles – is often hindered by logistics-related uncertainties (de Lima and Seuring, 2023). SP addresses these challenges by mitigating physical value loss through functional preservation and information loss through item-level visibility. In this study, "how" refers to the process of reconfiguring LCs from reactive functions into proactive management systems (Jayarathna *et al.*, 2024), while "why" addresses the theoretical logic of reducing material loss and information asymmetry to enable circularity. Following this, our research addresses two primary research questions.

RQ1. How does SP enhance LCs?

RQ2. What CE strategies can be supported by these enhanced LCs?

Our core contribution is a pathway-based framework that explains the systemic transition from SP data to circular outcomes. This study identifies the thematic pathways from micro-level PFs to macro-level LCs and their subsequent circular impacts. Specifically, we argue that SP enables the CE transition by reconfiguring LCs. Consequently, it responds to calls for a more analytically rigorous lens by integrating the R-imperative framework, which facilitates the delineation between design-led strategies and logistics-led interventions required to operationalise circularity at scale (de Lima and Seuring, 2023; Jegen *et al.*, 2025).

2. Conceptual background

This section synthesises three interconnected domains: SP-enhanced PFs, LCs and CE. To bridge the gap between technology and strategic outcomes, we utilise PFs as the micro-level unit of analysis to explain how item-level data generation reconfigures macro-level LCs. Then, we adopt the R-imperative framework to move beyond descriptive accounts to provide an operational understanding of why SP-enhanced interfaces facilitate the logistics flows (via LCs) required for a CE transition.

2.1 The micro-level: smart packaging-enhanced functionalities

This study uses SP-enhanced PFs as the micro-level unit of analysis where physical items reconfigure macro-level logistics processes. These functionalities represent the touchpoints where physical products interact with logistics operations (Robertson, 2016; Young *et al.*, 2023). Specifically, Robertson's (2016) classification is adopted as it captures the functional intersection between the package and the SC (da Silva Ponciano *et al.*, 2025; Sadeghi *et al.*, 2022), whereas material-based classifications fail to address this relationship required for CE transitions (Young *et al.*, 2023). As synthesised in Table 1, the integration of active and intelligent technologies transforms these static interfaces into dynamic data nodes capable of sensing, communicating, and reacting to an item's status (Lydekaityte and Tambo, 2020; Sadeghi *et al.*, 2022).

2.2 The macro-level: logistics capabilities

To map these micro-level PFs to the macro-level process layer, this study utilises Mentzer *et al.*'s (2004) framework of LCs. Theoretically grounded in the resource-based view and dynamic capabilities (DC), LCs are used instrumentally to explain how SP-enhanced PFs serve as reconfigurable resources that enable firms to sense (via condition monitoring), seize (via responsive logistics), and transform (via network reconfiguration) to achieve competitive advantage in fast-changing global and circular SCs (Mandal *et al.*, 2016). While the SC represents a network of member activities (Gligor and Holcomb, 2014), the LCs of individual members remain fundamental to broader network success (Mentzer *et al.*, 2004). This choice is analytically necessary because the four LC interfaces remain the dominant conceptualisations used to validate logistics integration and SC resilience (Jayarathna *et al.*, 2024; Mandal *et al.*, 2017). Crucially, information-management capabilities serve as the fundamental antecedent for integrating other logistics functions to master uncertainty and enable SC agility (Gligor and Holcomb, 2014). Furthermore, integrated LCs represent the dominant influence on a firm's ability to build resilience and manage the inherent complexity of circular systems (Mandal *et al.*, 2017). As shown in Table 2, these interfaces provide a theoretical grounding for this study to categorise and explain how item-level intelligence reconfigures LCs for CE transitions. In this study, LCs are analysed through their capacity to reconfigure the four primary logistics interfaces: information-management, supply-management, demand-management, and coordination, which act as the operational conduits for circularity.

2.3 The strategic-level: circularity through R-imperatives

The CE transition requires slowing, narrowing, and closing material loops. While the 9R framework provides the strategic hierarchy (Potting *et al.*, 2017), this study adopts the R-imperative framework (de Lima and Seuring, 2023; Jegen *et al.*, 2025) as the primary strategic lens. This shift is analytically necessary because R-imperatives cluster circular strategies based on their underlying SC design and flow requirements (Kirchherr *et al.*, 2017). Unlike purely hierarchical models, R-imperatives group the 9R strategies (see Appendix 1 for definitions) into three operational clusters: smarter use, lifespan expansion, and material application (de Lima *et al.*, 2022; Mostafayi Darmian *et al.*, 2026). In this study, these three imperatives serve as the primary classification for CE outcomes, allowing for an analysis of

Table 1. SP enhancement of PFs (classification criteria adapted from Robertson (2016))

PF	Description	SP enhancement – active packaging (AP) and intelligent packaging (IP)
Protection	To provide protection from external and internal impacts (barrier protection, mechanical protection), facilitate preservation from spoilage, and ensure security against tampering, pilferage, theft, fraud, and counterfeiting throughout the SC (da Silva Ponciano *et al.*, 2025; Robertson, 2016; Young *et al.*, 2023)	*AP* – Facilitates interactions between the item and its internal environment to absorb or release substances, thereby keeping items fresher for longer while guaranteeing nutritional attributes (Abekoon *et al.*, 2024; Sharma *et al.*, 2023) *IP* – Continuously monitors, records, and verifies product integrity through real-time sensing of internal and environmental conditions, integrity/tamper detection, and traceability/authentication features, enabling early risk detection and rapid intervention to maintain product protection (Abekoon *et al.*, 2024; Ahmed *et al.*, 2018; Sadeghi *et al.*, 2022)
Communication	To deliver diverse information in various forms to different SC stakeholders, including identifying and informing about the product, attracting attention and influencing perception, decision-making, branding, marketing and advertising (Lydekaityte and Tambo, 2020; Robertson, 2016; Sadeghi *et al.*, 2022; Young *et al.*, 2023)	*AP* – Indirectly contributes through functional compounds that may induce visible state changes indicating product condition (Barone *et al.*, 2021; Mesci *et al.*, 2024; Sadeghi *et al.*, 2022) *IP* – Converts product and environmental states (e.g. temperature, gas composition, location) into digital signals, enabling real-time monitoring, tracking and tracing, quality alerts, accessible product information, and data-driven decision-making across supply chain stakeholders and consumers (Abekoon *et al.*, 2024; Sadeghi *et al.*, 2022; Young *et al.*, 2023)
Convenience	To facilitate convenient handling including logistics (storage, transportation, distribution, warehousing, and stacking), retail (placement on shelves, inventory), consumption or utilisation (opening, re-opening, portability, storability), and disposal (Robertson, 2016; Sadeghi *et al.*, 2022; Young *et al.*, 2023)	*AP* – Indirectly contributes to maintain optimal internal package environment, prolonging product viability which may indirectly facilitate storage and distribution operations. (e.g. reducing the need for frequent manual quality inspections) (Firouz *et al.*, 2021; Sadeghi *et al.*, 2022) *IP* – Uses non-line-of-sight scanning and wireless data exchange to automate inventory capture and data flows, enabling real-time inventory management, streamlined handling operations, and data-driven optimisation of logistics and return processes (Abekoon *et al.*, 2024; Sadeghi *et al.*, 2022)
Containment	To serve as a source of containment by enclosing, enveloping, and holding goods together securely (da Silva Ponciano *et al.*, 2025; Robertson, 2016; Sadeghi *et al.*, 2022)	*AP* – Regulates the internal package environment (e.g. oxygen, moisture, gas) to stabilise product conditions and indirectly support containment by preventing degradation that could compromise package integrity (da Silva Ponciano *et al.*, 2025) *IP* – Affixes digital identifiers to primary, secondary, and tertiary units to monitor package integrity and detects breaches (e.g. damage, tampering), enabling timely intervention to maintain secure enclosure of a product (Abekoon *et al.*, 2024; Machiels *et al.*, 2021; Sadeghi *et al.*, 2022)

Source(s): Authors' own elaboration

Table 2. Summary of LCs as the macro-level analytical lens (classification criteria adapted from Mentzer *et al.* (2004))

LC interface	Description	Sub-capabilities	Key references
Information-management	Information technology and/or connectivity that enables firms to acquire, analyse, store, and share tactical and strategic information internally and with partners	Acquiring, storing, analysing information (IN1); Sharing and exchanging information (IN2); Supporting decision-making (IN3); Securing information and trust (IN4)	Gligor and Holcomb (2014), Jayarathna *et al.* (2024), Mandal *et al.* (2017), Mentzer *et al.* (2004)
Supply-management	The management of the logistics function including total cost minimisation, effective time and resource management, and the standardisation of logistics activities	Proactive or creative logistics solutions (SP1); Simplification and standardisation of key logistics activities (SP2); Timeliness and time efficiency (SP3); Human labour minimisation (SP4); Resource minimisation (SP5); Other cost minimisation (SP6)	Gligor and Holcomb (2014), Jayarathna *et al.* (2024), Mandal *et al.* (2017), Mentzer *et al.* (2004), Rajaguru *et al.* (2022)
Demand-management	Distinctive product or service offerings focused on fulfilling customer requirements through high-quality, responsive, and flexible logistics; also called customer-focused, value-added, or customer integration capabilities	Flexibility in operational circumstances (DM1); Responsiveness to customer requirements (DM2); Timeliness in logistics operations (DM3); Availability of operational coverage (DM4); Delivery quality conforming with customer requirements (DM5); Communication with customers (DM6)	Gligor and Holcomb (2014), Jayarathna *et al.* (2024), Mandal *et al.* (2017), Mentzer *et al.* (2004), Rajaguru *et al.* (2022)
Coordination	Internal and external coordination; integration of internal and external organisational elements to align actions and achieve the goals of the logistics operation; ability to communicate and collaborate	Standardisation – i.e. cross-functional policies and procedures (CO1); Simplification (CO2); Compliance – i.e. adherence to established policies, internal procedures, and external regulations (CO3); Structural adaptation – i.e. network structure, and deployment of resources (CO4); Visibility (CO5)	Gligor and Holcomb (2014), Jayarathna *et al.* (2024), Mandal *et al.* (2017), Mentzer *et al.* (2004)

Source(s): Authors' own elaboration

how and why logistics interventions facilitate specific circular pathways (see Appendix 1, Table A1 for details on the R-imperative and 9R). As synthesised in Table 3, this clustering provides a clear delineation between forward-focused design strategies and the reverse-focused operational core of circularity.

Upstream "smarter use" strategies are primarily design-led with LCs supporting optimised forward flows. In contrast, the operational core – "lifespan expansion" and "material application" – is fundamentally enabled through reconfigured LCs. However, these models require robust logistics infrastructures to manage the physical complexity of take-back, sorting, quality triage, and supply-demand matching (Morgan *et al.*, 2016; Mostafayi Darmian *et al.*, 2026). Currently, the reverse-focused models are hindered by critical uncertainties

Table 3. Analytical mapping of R-imperative framework to LCs

R-imperative	R-strategies	Operational requirements and LC interfaces	Key references
Smarter use	Refuse (R0) Rethink (R1) Reduce (R2)	Upstream waste prevention relying on supply-management and demand-management interfaces to optimise forward flows and reduce overproduction (including unnecessary product waste), as well as support from information-management interface to optimise the connection between supply and demand	Gligor and Holcomb (2014), Jayarathna *et al.* (2024), Jegen *et al.* (2025), Mandal *et al.* (2017), Mentzer *et al.* (2004), Mostafayi Darmian *et al.* (2026), Rajaguru *et al.* (2022)
Lifespan expansion	Reuse (R3) Repair (R4) Refurbish (R5) Remanufacture (R6) Repurpose (R7)	Reverse logistics requiring the information-management interface to verify asset condition and the coordination interface for triage and sorting, resolving information asymmetry	Carlos and de Mattos (2025), Gligor and Holcomb (2014), Jayarathna *et al.* (2024), Jegen *et al.* (2025), Mandal *et al.* (2017), Mentzer *et al.* (2004)
Material application	Recycle (R8) Recover (R9)	Scalable recovery of material value requiring the coordination interface, with support from the information-management interface, to manage high-volume return flow and material purity	de Lima *et al.* (2022), Gligor and Holcomb (2014), Jayarathna *et al.* (2024), Mandal *et al.* (2017), Mentzer *et al.* (2004), Mostafayi Darmian *et al.* (2026)

Source(s): Authors' own elaboration

regarding the quality, quantity, and timing of returned assets (de Lima and Seuring, 2023). Consequently, circularity is both a material and an informational challenge. SP addresses this by (1) mitigating physical value loss through functional preservation and (2) mitigating information loss by providing item-level visibility.

As integrated LCs are a dominant influence on a firm's ability to manage circular complexity, they require both functional preservation and real-time visibility enabled by SP to resolve primary implementation barriers (Carlos and de Mattos, 2025; Fatorachian and Kazemi, 2021). Through these SP-enhanced LCs, loop-closing strategies can move beyond sequential siloed approaches towards the concurrent design of forward and reverse flows, facilitating the economic viability and strategic sustainability of circularity.

3. Methodology

This study employed a theory-informed SLR, guided by established LSCM research principles to ensure transparency, rigour, and reproducibility (Durach *et al.*, 2017; Seuring *et al.*, 2020). Moving beyond descriptive summaries, the methodology was designed to provide a detailed explanation of how and why SP reconfigures logistics activities and enables CE transitions. This approach facilitated both theory refinement (deductive-internal) by examining how SP operationalises LCs, and theory extension (deductive-external) by linking these enhancements to the strategic requirements of the CE transition (Seuring *et al.*, 2020).

3.1 Sampling and selection strategy

Following the six-step SLR proposed by Durach *et al.* (2017), RQs were defined in the first step. Specifically, RQ1 aimed to capture the "how" by examining the operational reconfiguration of macro-level LCs triggered by micro-level SP-enhanced PFs. RQ2 addressed the strategic "why" by identifying the circular outcomes (R-imperatives) enabled by these enhanced capabilities, explaining the logic of how resolving information asymmetry and material loss facilitates CE transitions.

Step 2 operationalised selection criteria via the PEO framework (Population, Exposure, Outcome) (Khan *et al.*, 2003), restricting the population to logistics or SC contexts where packaging is a strategic resource, the exposure to SP-logistics linkages, and the outcome to an identifiable circular R-strategies. The sample records included peer-reviewed articles, chapters, and reviews published in English through December 2025, reflecting the strong growth trend in recent literature. Step 3 comprised a comprehensive search of Scopus and Web of Science using a three-block keyword strategy targeting the intersection of SP, logistics, and circular R-strategies.

In Step 4, the baseline sample was refined through a two-stage screening process to minimise selection bias (Durach *et al.*, 2017). Initially, four researchers independently screened titles and abstracts against exposure criteria, with “maybe” cases reassessed by an independent team member to ensure inter-rater reliability. A subsequent full-text assessment against outcome criteria resolved ambiguities regarding the SP-LC-CE linkage through group consensus, resulting in a final synthesis sample of 59 articles (see Figure 1).

3.2 Data analysis and synthesis

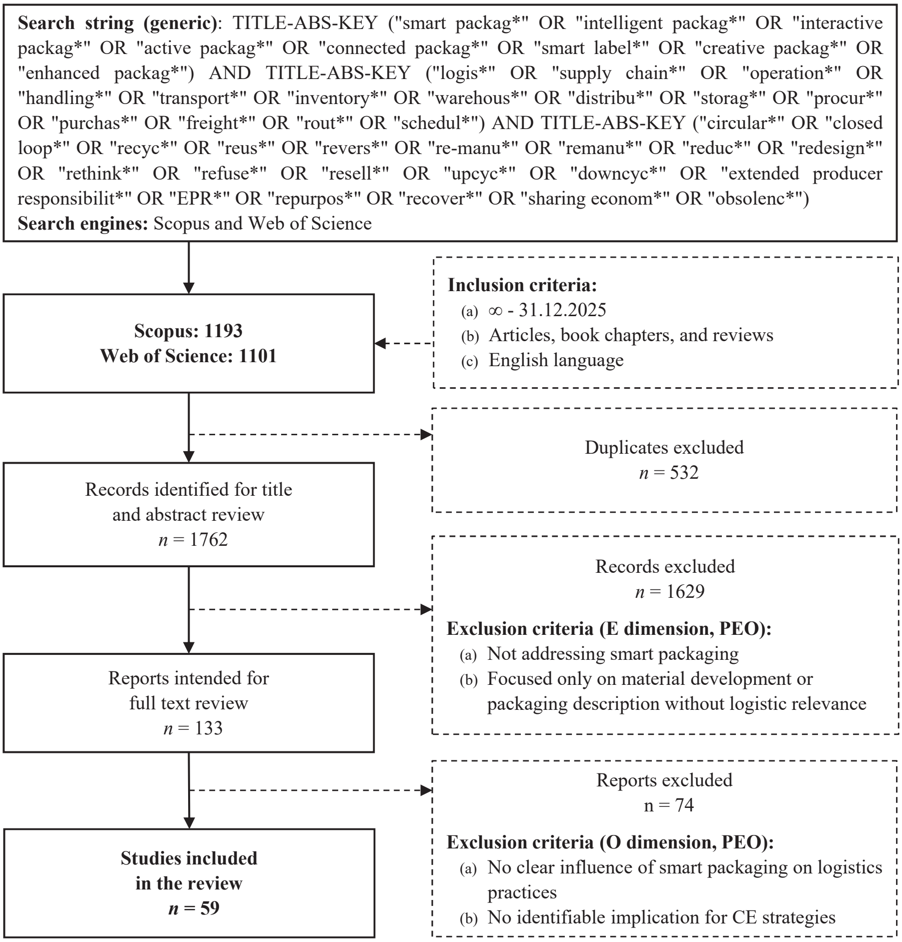
Data analysis and framework development (Step 5) followed a two-phase synthesis designed to transition from the micro-level unit of analysis to the macro-level process layer, and finally to strategic circular outcomes. In the first phase, the specific mechanisms through which SP reconfigures micro-level PFs were inductively derived from the analysis of 59 reviewed articles (list of full references in Supplementary Material 1). Coded data associated with each primary PF were systematically examined and grouped into recurring themes, which were subsequently defined as packaging sub-functionalities (see Appendix 2 for definitions and further explanation). These sub-functionalities were subsequently mapped to logistics sub-capabilities across the four LC interfaces using an analysis matrix, with mappings recorded only when studies explicitly linked SP technology or its functionality to a change in a specific logistics sub-capability (see details in Supplementary Material 2).

In the second phase, these reconfigured LCs were synthesised through the lens of the R-imperative framework to determine the specific circular strategies enabled by these enhanced capabilities. This involved systematically analysing how each logistics sub-capability contributes to CE outcomes and assigning these contributions to corresponding R-strategies based on the reported operational effects (e.g. waste prevention, reuse facilitation, or recycling support), as detailed in Supplementary Material 3. To ensure analytical rigour and move beyond the identification of isolated variables, we utilised axial coding in NVivo during first and second stages to identify the sequences and linkages between these layers (Durach *et al.*, 2017).

This methodological choice was essential to construct a systemic mapping of reconfiguration, tracing how a technological trigger (micro-level PFs) reconfigures a logistics process (macro-level LCs) to enable a specific circular outcome (strategic-level R-imperative). This process provided the analytical foundation for the framework synthesis grounded in a theoretically sound evidence base (Tranfield *et al.*, 2003). Finally, results were synthesised into a multi-layered framework (Step 6). The following findings present four thematic pathways where SP-enhanced PFs are systematically linked to specific LC interfaces (RQ1) to address the operational and informational requirements of the R-imperatives (RQ2).

4. Findings

To synthesise the complex relationships between SP-enhanced functionalities, LCs and their contribution to R-imperatives, Table 4 provides an analytical roadmap derived from two-stage qualitative coding and analysis where we identified the core configurations that appear most



Source(s): Authors' own elaboration

Figure 1. SLR search and selection process

Table 4. Consolidated summary of thematic mapping

Thematic pathway	Dominant sub-PFs	Dominant sub-LCs	R-imperatives	Dominant R-strategies
Predictive logistics management and dynamic optimisation	CM1, CM2, PT1, PT2, and PT3	IN1, IN3, SP1-SP6, DM1, DM2, DM3, and DM4	Smarter use	R2
Autonomous and scalable reverse flows	CM1, CV1, CV2, CV3, and CT1	SP1-SP6, CO1, CO2, and CO4	Lifespan expansion and material application	R3, R6, R8
Systemic trust and quality of material streams	CM1, PT2, PT5, PT4, and PT6	IN4, CO3, CO5, and SP1	All R-imperatives	R2, R3, R8
Collaborative value co-creation	CM1, CM2, PT2, and CV4	IN2, SP1, DM2, DM5, and DM6	All R-imperatives	R2, R3, R8

Source(s): Authors' own elaboration

consistently as effective enablers of circularity. This synthesis reveals four thematic pathways: (1) proactive logistics management and dynamic optimisation, (2) autonomous and scalable reverse flows, (3) systemic trust and quality of material streams, and (4) collaborative value co-creation.

Following the DC framework (Teece, 2007), each pathway tracks the transition from sensing (data acquisition) to seizing (operational intervention) and reconfiguring (systemic change). To ensure clarity, each section foregrounds a primary mechanism representing the most significant process within that pathway. This structure differentiates between pathways driven by seizing capabilities (process-level interventions in Pathways 1 and 3) and those requiring reconfiguring capabilities (system-level changes in Pathways 2 and 4). The following sections detail these primary mechanisms, using secondary elements as illustrative support to demonstrate how SP-enabled capabilities achieve circular outcomes.

4.1 Proactive logistics management and dynamic optimisation

SP serves as a critical enabler for shifting logistics from a reactive operational function to a proactive management system. This pathway addresses the loss of materials and information by transforming traditional information-management capabilities into dynamic assets for circularity. This shift is underpinned by foundational sensing capabilities, where SP-enhanced functionalities allow firms to move beyond static labelling to acquire, store, and analyse item-level data regarding product freshness and physical integrity (Dodero *et al.*, 2021; Du *et al.*, 2025; Vanderroost *et al.*, 2014; Wang *et al.*, 2019). Specifically, SP-enhanced protection functionalities ensure physical integrity throughout the forward flow, providing the environmental control necessary to preserve product value. By embedding sensors and unique data carriers, the technological layer transforms the packaging into an active data node capable of monitoring thermal history and atmospheric conditions (Aguiar *et al.*, 2022; Mohebi and Marquez, 2015; Taoukis, 2010). These capabilities reduce the uncertainty regarding an item’s remaining shelf-life, providing the accurate data needed to mitigate the information asymmetry that leads to material waste across the SC (Jayarathna *et al.*, 2024).

The primary mechanism driving this pathway is the development of seizing capabilities, specifically foregrounded using predictive decision-support models in the supply-management interface. By feeding real-time data into proactive decision models, firms move beyond simple detection to anticipate anomalies, such as temperature deviations and fraudulent route changes, and predict spoilage patterns before material value is lost (Mostaccio *et al.*, 2023; Yang *et al.*, 2024). High-fidelity data from nano-sensors and AI-driven indicators provide up to 97.5% accuracy in identifying freshness stages, offering the analytical precision required for seizing interventions and decision support in a timely manner (Du *et al.*, 2025; Rajan and Wani, 2025). This capability allows managers to utilise AI and machine learning to replace rigid, time-based protocols with dynamic logistics solutions tailored to the actual state of the product (Fernandez *et al.*, 2023; Jia *et al.*, 2025). By synchronizing environmental sensing with analytical insights, firms align product status with logistics planning, ensuring that material value is preserved (Alam *et al.*, 2021; Upadhyay *et al.*, 2024).

Consequently, these interventions facilitate reconfiguring capabilities in supply-management and demand-management interfaces, where firms implement dynamic operational flexibility and process optimisation in the forward flow. This allows shipments to be prioritised or rerouted in transit based on actual degradation rates, enhancing responsiveness to both environmental conditions and customer needs (Fernandez *et al.*, 2023; Kamau *et al.*, 2025). Furthermore, SP enables firms to influence demand by transforming quality data into market intelligence. Retailers can use real-time shelf-life and quality data from sensors to trigger dynamic pricing, accelerating the sale of at-risk items (Heising *et al.*, 2017; Jia *et al.*, 2025; Taoukis, 2010). These capabilities, supported by streamlined inventory management through non-line-of-sight scanning, allow firms to eliminate the manual errors and time lags inherent in high-volume environments (Abekoon *et al.*, 2024; Semunab *et al.*, 2016). Moreover, they enable the First-Expired-First-Out (FEFO) systems, providing the operational precision required to make circular models economically competitive and prevent systemic waste (Ahmed *et al.*, 2018; Ganeson *et al.*, 2023; Lu *et al.*, 2025). Ultimately, the integration of these capabilities effectively mitigates the loss of materials and information across SC and operationalise the "smarter use" (reduce-R2) imperative (Kabadurmus *et al.*, 2023; Zhang *et al.*, 2025). Therefore, we propose:

Pathway 1 (P1): SP-enhanced *protection* and *communication* functionalities reconfigure the *information-management, supply-management, and demand-management* interfaces into proactive logistics management systems and dynamic optimisation by resolving information asymmetry in forward flows, thereby enabling the *smarter use* imperative.

4.2 Autonomous and scalable reverse flows

SP-enhanced functionalities are essential for transitioning from manual, niche-scale recovery to autonomous and scalable reverse flows. The primary mechanism driving this pathway is the development of reconfiguring capabilities that enable network structural adaptation and scalability, which provides the operational threshold necessary to maintain assets in high-value reverse flows. This pathway prevents material and information loss by industrialising the identification and routing processes required for circular loops.

This pathway is underpinned by foundational sensing capabilities, where SP establishes the identity, provenance, and condition of returned items. Through SP-enhanced communication functionalities (i.e. using unique digital identifiers and data carriers), firms can implement standardised governance and the acquisition of item-level data for the return and re-entry of reusable items among SC actors, such as ownership history and material composition (Abekoon *et al.*, 2024; Al-Thani *et al.*, 2025; Kamau *et al.*, 2025). For example, the integration of Digital Product Passports (DPPs) facilitates the end-to-end exchange of item-level lifecycle data (Singh *et al.*, 2025). In specialised sectors like pharmaceuticals, these protocols establish a verifiable record of storage history to ensure item integrity (Gerrans *et al.*, 2023). By resolving uncertainty regarding an item's origin and history, these sensing capabilities provide the evidence required for the safe recovery of post-consumer assets (Kamboj *et al.*, 2025; Singh *et al.*, 2025).

These data streams enable seizing capabilities within the coordination and supply-management interfaces through automated triage and processing. By combining convenience functionalities and unitised containment with standardised carriers and digital watermarking, firms execute high-fidelity sorting and assess asset integrity with near-instantaneous precision (Machiels *et al.*, 2021; Rajan and Wani, 2025). This capability mitigates labour-intensive manual assessments, traditionally a major bottleneck, and significantly increases the throughput of recovery facilities (Ahmed *et al.*, 2018; Gerrans *et al.*, 2023). Consequently, this ability to seize recovery opportunities overcomes the operational delays that prevent reverse flows from achieving industrial speeds, thereby ensuring the economic feasibility of circular strategies (Ahmed *et al.*, 2018; Fernandez *et al.*, 2021; Gerrans *et al.*, 2023; Machiels *et al.*, 2021).

As previously mentioned, the primary mechanism of this pathway is the development of reconfiguring capabilities that enable the structural adaptation of the supply-management and coordination interfaces. While circularity is often hindered by the geographic uncertainty and transport costs of decentralised returns, SP reconfigures the network architecture into a flexible, scalable loop. This involves feeding empirical condition and location data into decision-support models to manage collection, consolidation, and dynamic routing (Gerrans *et al.*, 2023; Jia *et al.*, 2025; Kamau *et al.*, 2025; Lu *et al.*, 2025). By synchronising data between actors and eliminating manual evaluation, this transformation achieves system-wide cost minimisation (Ahmed *et al.*, 2018; Rajan and Wani, 2025; Semunab *et al.*, 2016). Ultimately, these reconfiguring capabilities effectively resolve information asymmetry across the reverse logistics network, providing the architecture required to operationalise the "lifespan expansion" (reuse-R3 and remanufacture-R6) and "material application" (recycle-R8) imperatives at an industrial scale (Gerrans *et al.*, 2023; Kamboj *et al.*, 2025; Machiels *et al.*, 2021; Zhang *et al.*, 2025). Therefore, we propose:

Pathway 2 (P2): SP-enhanced *communication*, *convenience*, and *containment* functionalities reconfigure the *supply-management* and *coordination* interfaces into autonomous reverse flows by unitising assets and reducing the operational cost of recovery, thereby enabling the *lifespan expansion* and *material application* imperatives.

4.3 Systemic trust and quality of material streams

While P1 and P2 address operational optimisation and scalability, the CE transition is frequently hindered by a lack of trust among SC actors. Accordingly, SP-enhanced functionalities are fundamental to establishing the verifiable transparency for systemic trust required for high-value circularity. The primary mechanism driving this pathway is the development of seizing capabilities related to immutable verification and auditing, which allow firms to transition from trust-based to evidence-based models that mitigate fraud, theft, and counterfeiting. This pathway addresses the loss of materials and information by providing a secure record of an item’s lifecycle, thereby resolving the lack of trust regarding the environmental history and material purity of returned assets.

This pathway is underpinned by foundational sensing capabilities, where security-focused protection and communication functionalities, such as blockchain-linked RFID, holograms, and tamper-evident seals, ensure that provenance data remain unalterable (Davidescu *et al.*, 2025; Endara *et al.*, 2023; Zuo *et al.*, 2022). These capabilities are further enhanced by condition monitoring, where the package captures an objective history of temperature, moisture, and chemical exposure (Ahmed *et al.*, 2018; Matan *et al.*, 2024). By providing continuous visibility of product location and quality variables, these sensing capabilities reduce the uncertainty regarding material integrity and close the information gaps that traditionally leads to material leakage and premature disposal.

These data streams enable the primary seizing capabilities within the information-management and coordination interfaces through the creation of digital audit trails. By replacing best-guess assessments with digital verification, firms can seize the proof required to satisfy safety-critical requirements in multi-actor networks, facilitate stakeholder collaboration and prevent the downcycling of high-value materials (Al-Thani *et al.*, 2025; Gerrans *et al.*, 2023; Mostaccio *et al.*, 2023; Yang *et al.*, 2024). This capability allows firms to dynamically reroute assets based on their specific environmental exposure and residual safety margins rather than relying on chronological stock rotation (Abekoon *et al.*, 2024; Du *et al.*, 2025). Furthermore, the integration of granular data on material composition into decision-support models enables firms to replace speculative manual sorting with precision identification (Al-Thani *et al.*, 2025; Htun *et al.*, 2023; Yang *et al.*, 2024). By synchronising item-level evidence with logistics processes, firms resolve the information asymmetry between disparate actors, ensuring that only items with verified storage history are reintegrated into high-value streams.

This pathway culminates in reconfiguring capabilities that evolve the information-management and coordination logistics interfaces into a precision material harvesting system. These capabilities generate the auditable proof required to satisfy strict regulatory standards, effectively turning the package into a digital certificate of circular eligibility (Gerrans *et al.*, 2023; Kamboj *et al.*, 2025). This systemic shift replaces subjective visual inspections with verifiable data, providing the structural transparency required to safely scale circular operations (Butuc *et al.*, 2025; Singh *et al.*, 2025). Ultimately, these capabilities resolve information asymmetry regarding provenance and integrity, ensuring that materials retain their highest utility across multiple lifecycles (Davidescu *et al.*, 2025; Singh *et al.*, 2025; Yang *et al.*, 2024). This allows firms to operationalise the “smarter use” (reduce-R2), “lifespan expansion” (reuse-R3), and “material application” (recycle-R8) imperatives simultaneously. Therefore, we propose:

Pathway 3 (P3): SP-enhanced *protection* and *communication* functionalities reconfigure the *information-management* and *coordination* interfaces to establish systemic trust and facilitate high-quality material streams by resolving information asymmetry regarding material purity and lifecycle provenance, thereby enabling *all three R-imperatives*.

4.4 Collaborative value co-creation

The findings reveal that SP-enhanced functionalities serve as a foundation for transitioning from traditional, firm-centric SCs toward collaborative value co-creation platforms. The primary mechanism driving this pathway is the development of reconfiguring capabilities related to consumer role transformation, which fundamentally redefines their position within the logistics network. This pathway addresses the loss of materials and information by bridging the information gap between industrial actors and end-users to facilitate circular loops through direct engagement and decentralised decision-making.

This transformation is underpinned by foundational sensing capabilities, where communication functions and digital data carriers (e.g. QR codes, near-field communication) create a direct digital link for information flow. These capabilities allow consumers to access real-time data regarding product origin, safety status, and usage instructions via personal devices (Ahmed *et al.*, 2018; Du *et al.*, 2025; Kamau *et al.*, 2025). Simultaneously, SP-enhanced protection functionalities ensure the physical integrity of the product, providing the tangible safety assurance that supports these digital credentials. By offering transparent credentials and sourcing data, SP-enabled information-management interfaces empower consumers to make informed choices and align their consumption with circular commitments (Davidescu *et al.*, 2025; Kamboj *et al.*, 2025; Uysal-Unalan *et al.*, 2024). These sensing capabilities resolve provenance uncertainty and mitigate information asymmetry at the point of purchase, providing the foundational trust required to prevent the premature disposal of viable products.

These data streams enable seizing capabilities within the demand-management interface through direct digital engagement and condition-driven interventions. By matching the physical state of the package to sustainability expectations, firms can align logistics quality with evolving customer requirements for freshness and safety (Fernandez *et al.*, 2023; Rajan and Wani, 2025; Versino *et al.*, 2023). When consumers interact with smart labels, the system captures real-time signals that trigger dynamic interventions, such as storage advice, usage recommendations, or immediate price markdowns, to prevent the item from becoming waste (Du *et al.*, 2025; Zhang *et al.*, 2025). For green consumer segments, these seizing capabilities foster high-engagement connections by resolving the information asymmetry between industrial actors and consumers (Alves *et al.*, 2023; Davidescu *et al.*, 2025). Consequently, active consumer participation ensures that material value is preserved through data-driven problem anticipation (Alam *et al.*, 2021; Upadhyay *et al.*, 2024; Zhang *et al.*, 2025).

Ultimately, these processes culminate in the primary reconfiguring capabilities that transform the supply-management and demand-management interfaces by integrating the consumer as a functional logistics node in circular SCs. This structural shift reconfigures the logistics architecture by decentralising decision-making and utilising the consumer to perform essential tasks such as initial grading, sorting and automatic data-logging (Gerrans *et al.*, 2023; Singh *et al.*, 2025). These capabilities allow the network to scale by lowering the physical and cognitive effort required for participation, establishing a collaborative return system where consumers actively sustain the circular loop (Machiels *et al.*, 2021; Singh *et al.*, 2025). Finally, these reconfiguring capabilities effectively resolve information asymmetry across the stakeholder interface, providing the collaborative structure required to operationalise the “smarter use” (reduce-R2), “lifespan expansion” (reuse-R3), and “material application” (recycle-R8) imperatives simultaneously (Al-Thani *et al.*, 2025; Barone *et al.*, 2021; Butuc *et al.*, 2025; Kamboj *et al.*, 2025). Therefore, we propose:

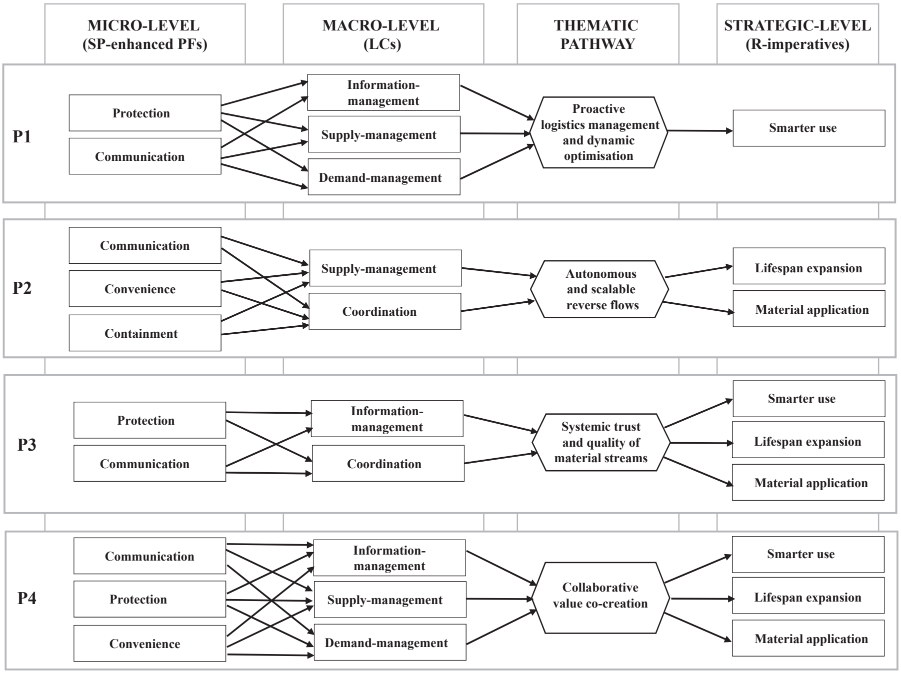
Pathway 4 (P4): SP-enhanced *communication, protection,* and *convenience* functionalities reconfigure the *information-management, supply-management* and *demand-management* interfaces into collaborative platforms by integrating the consumer as a functional logistics node, thereby facilitating *all three R-imperatives*.

5. Discussion

The synthesis of our findings demonstrates that SP serves as the critical technological bridge for simultaneously addressing CE challenges of physical value and information loss. While design-led strategies focus on material prevention, our analysis confirms that the operational core of circularity – recovering and extending product lifecycles – is fundamentally hindered by logistics-related uncertainties. By mitigating material degradation through functional preservation and resolving information asymmetry through item-level visibility, SP reconfigures LCs from reactive operational functions into proactive management systems. To visualise these pathways, we propose a multi-layered conceptual framework (see Figure 2). It maps the transition from the micro-level technological enabler (SP-enhanced PFs) to the macro-level reconfiguration of LCs, which ultimately operationalises the strategic-level CE outcomes (R-imperatives) identified in the four thematic pathways (P1-P4).

5.1 Theoretical contributions

The primary theoretical contribution of this study is the development of a multi-layered conceptual framework that explains the "how" and "why" behind SP-enabled circularity. By returning to the analytical premise that circularity is fundamentally both a material and an information problem, we demonstrate that SP-enhanced interfaces resolve these challenges by



Source(s): Authors' own elaboration

Figure 2. Multi-layered conceptual framework of SP-enabled circularity

transitioning SCs from reactive recovery to proactive management systems. This research contributes to LSCM theory in four ways.

First, we demonstrate how SP-enhanced functionalities operationalise latent logistics DC. While LCs are theoretically recognised as DC, their execution in circular systems is traditionally hindered by a lack of item-level visibility. By providing the necessary data to sense quality and seize recovery opportunities, SP triggers the functional preservation required to mitigate physical value loss while simultaneously resolving the information asymmetry that leads to systemic waste. Consequently, it effectively transforms latent capabilities into proactive data-driven management systems.

Second, we identify the information-management interface as the foundational antecedent for circular logistics. By generating item-level data, it allows other interfaces to manage closed-loop complexity. This establishes a theoretical hierarchy where the effective operationalisation of the information-management interface serves as a prerequisite for the physical reconfiguration of the SC required for circularity. This hierarchy clarifies that the CE transition is contingent upon the digital maturity of the logistics information layer.

Third, this study clarifies the role of the containment functionality as the physical anchor that operationalises the physical-digital bridge. While previous SP research often overlooks containment or views it as a static integrity-maintaining function, we conceptualise it as the physical-digital unitiser necessary for scaling autonomous reverse flows. We argue that while communication functions (e.g. tags and sensors) create the digital clusters of items, containment provides the structural foundation required to scale these clusters within industrial logistics. By ensuring that aggregated units remain physically intact and digitally identifiable as a single entity during high-volume handling, containment preserves the identity linkage between items and their digital representations. It is this synchronisation that allows individual item intelligence to be effectively operationalised within network-level coordination. Consequently, containment is transformed from a static integrity-maintaining function into a proactive enabler of scalable reverse flows.

Fourth, SP transforms the downstream demand-management interface into a collaborative bridge facilitating multi-imperative circularity. By integrating the consumer as a functional value co-creator, SP allows a single digital interaction to simultaneously activate pathways for all R-imperatives through waste prevention ("smarter use"), asset recovery ("lifespan expansion"), and material purity ("material application").

Finally, we identify theoretical boundaries regarding the scope of logistics-led interventions. While SP provides robust support for the logistics-led recovery strategies – i.e. industrial-scale reuse, remanufacture, and recycle, there is negligible evidence connecting these capabilities to the design-led strategies such as repair and refurbish. This gap indicates that such high-touch strategies may rely more on fundamental product design (e.g. modularity) and localised service ecosystems than on the logistics reconfiguration enabled by item-level intelligence. This boundary suggests that SP is a critical enabler for industrialising the CE but cannot substitute for upstream design interventions in strategies where material complexity exceeds informational resolution.

5.2 Practical implications

For practitioners, this study provides a concrete roadmap for leveraging SP to achieve tangible sustainability and operational benefits by reducing waste and closing information gaps inherent in circular loops. For policymakers, these findings highlight SP as a key enabling tool for future policy initiatives, such as Extended Producer Responsibility, to verify compliance and ensure material purity in recycling streams. Interpreting the findings through the lens of logistics reconfiguration, we identify four strategic avenues for implementation.

First, logistics and supply chain managers can utilise SP-enhanced sensing to transition from rigid, time-based inventory models to dynamic, quality-controlled systems, such as data-driven FEFO. This shift allows firms to minimise spoilage and maximise resource utility by rerouting products in transit based on their actual condition, effectively achieving the "smarter use" imperative at the operational level. This capability transforms the information interface into a proactive management tool that anticipates waste before it occurs.

Second, to overcome the high operational costs and complexity of reverse logistics, managers should prioritise the integration of automated sorting with unitised containment. In the reverse flow, the integration of non-line-of-sight scanning and standardised data carriers lowers the per-unit cost of processing, eliminating labour-intensive manual assessments. By treating the package as a unified physician and digital unit, firms can achieve the bulk handling required for industrial-scale recovery. This ensures that individual assets remain identifiable and seizable for high-speed triage within high-volume environments. Therefore, by automating the identification and sorting of returns, SP-enhanced LCs make the high-value "lifespan expansion" imperative – i.e. reuse and remanufacture – economically competitive with linear models by achieving the operational threshold required for network-level scalability.

Third, SP provides a verification layer to build systemic trust within circular networks, particularly in high-risk sectors such as pharmaceuticals and food. Managers can leverage tamper-evident and condition-monitoring functions to provide a verifiable audit trail of the item's storage and environmental history. This transparency provides the objective evidence required to satisfy safety standards and regulatory requirements. By providing a secure record of material purity, SP ensures that secondary resources maintain their highest value and prevents the downcycling of high-quality materials.

Lastly, for marketing and product managers, SP provides a direct digital link to the consumer, turning them into an active participant in circular loops. By providing personalised rewards and clear, item-level disposal instructions via mobile applications, firms can simplify the consumer's role in the recovery process. This digital engagement reduces the effort required for participation, ensuring higher rates of high-quality material returns. Collectively, these capabilities transform circularity from a logistical burden into a data-driven competitive advantage, allowing firms to synchronise forward and reverse flows into a single, optimised ecosystem.

6. Conclusion

This study systematically explored the pathways through which SP simultaneously enhances LCs to address the CE challenges of physical value and information loss. By synthesising fragmented literature into a multi-layered conceptual framework, we have demonstrated that SP is more than a data-collection tool. It acts as a foundational reconfigurable resource that transforms LCs from reactive operational functions into proactive management systems.

The study indicates that the enhancement of LCs is a multi-stage process triggered by micro-level SP-enhanced PFs. We have clarified that the information-management interface serves as the foundational antecedent, providing the functional preservation and item-level visibility required to sense quality degradation and seize recovery opportunities. These capabilities reconfigure the supply-management, demand-management, and coordination interfaces, allowing firms to manage the inherent complexity of closed-loop systems. Through these enhanced capabilities, the logistics network can effectively support the three strategic R-imperatives – smarter use, lifespan expansion, and material application. Specifically, our analysis identified four thematic pathways – (1) proactive logistics management and dynamic optimisation, (2) autonomous and scalable reverse flows, (3) systemic trust and quality of material streams, and (4) collaborative value co-creation – as the dominant configurations through which SP reconfigures the LCs to achieve effective and industrial-scale circularity.

While this review provides a rigorous foundation, several critical boundaries and gaps remain. First, our analysis identified a significant sector bias, with 90% of the synthesised articles focused on the food industry. This dominance is expected, as the food sector is a high-volume industry where packaging is used to manage strict shelf-life limits and perishable goods. Despite a strong baseline, future research should explore how these technologies work in technical sectors like electronics or textiles, where products do not spoil but have complex recycling and recovery cycles. Second, there is a notable theoretical boundary regarding the scope of logistics-led interventions. We found negligible evidence connecting SP-enhanced capabilities to the design-led strategies such as repair and refurbish. This indicates a research gap in understanding how item-level intelligence can support such circular strategies that currently rely more on product design than on logistics reconfiguration. Finally, as 73% of our synthesis base comprised literature reviews, there is a pressing need for empirical validation. Future studies should employ longitudinal case designs or large-scale quantitative assessments to validate the causal strength of the proposed pathways (P1-P4). Specifically, exploring the dynamics of human collaborative value co-creation would further refine our understanding of the consumer as a functional logistics node. By addressing these gaps, future research can build upon this framework to transition circularity from a series of isolated initiatives into a synchronised data-driven ecosystem facilitated by SP.

Acknowledgments

The authors are grateful to Professor Erik Sandberg and Professor Maria Björklund, Department of Management and Engineering, Linkoping University, for their insightful comments on earlier drafts of this manuscript. This research was supported by Svenska Forskningsrådet Formas, and by National Science Centre, Poland for Yash Chawla.

(The Appendix follows overleaf)

Appendix 1

Table A1. Operational definitions and LSCM implications of circular strategies

R-imperative	R-strategy	Definition and logistical scope	LSCM implication
Smarter use	Refuse (R0)	Avoiding unnecessary products or materials and their associated flows by abandoning functions or switching to non-material solutions	Requires upstream avoidance of non-essential flows and strategic procurement choices to prevent waste at the source
	Rethink (R1)	Making product use more intensive, often through sharing platforms or multi-functional design	Necessitates demand-management to optimise the connection between supply and demand via service-based models
	Reduce (R2)	Using fewer resources and generating less waste per unit of output through increased efficiency	Focuses on preventing systemic leakage through spoilage reduction, fewer handling steps, and optimised execution
Lifespan expansion	Reuse (R3)	Using a discarded but functional product again for its original purpose	Depends on functioning return/collection loops, eligibility checks, and condition verification to enable multiple cycles
	Repair (R4)	Fixing faults in a broken product so it can be utilised with its original function	Requires diagnostic triage and routing to repair centres supported by parts and service logistics
	Refurbish (R5)	Restoring an old product and bringing it up to date through extensive reconditioning	Involves grading, quality assurance, and controlled reintegration into appropriate secondary market channels
	Remanufacture (R6)	Rebuilding a product to ‘as new’ condition using recovered cores and new parts	Requires core acquisition, disassembly, testing, and certification within a robust reverse network design
	Repurpose (R7)	Using a discarded product or its components for a function different from the original	Necessitates cross-actor coordination and matching criteria to align residual value with new alternative functions
Material application	Recycle (R8)	Processing materials to obtain secondary raw materials of high- or low-grade quality	Requires collection consolidation at scale, strict contamination control, and high material purity to ensure economic viability
	Recover (R9)	Incinerating materials with energy recovery when higher value retention is not feasible	Focuses on compliant routing and documentation for residual streams to ensure safe, regulated final processing

Source(s): Adapted from Batista *et al.* (2018), Carlos and de Mattos (2025), de Lima and Seuring (2023), Jegen *et al.* (2025), Mostafayi Darmian *et al.* (2026), Potting *et al.* (2017)

Appendix 2

The high-level packaging functionalities were adopted from Robertson (2016), providing an established conceptual framework for categorising packaging roles. This step ensured theoretical consistency and alignment with widely recognised packaging literature. In contrast, the packaging sub-functionalities in Table A2 were inductively derived from the analysis of 59 reviewed articles, whereby coded data were systematically examined and grouped into recurring themes. This involved iterative comparison of codes within each primary functionality, consolidation of conceptually similar codes, and abstraction into higher-order thematic categories, i.e. packaging sub-functionalities. Given the observed inconsistency and overlap in terminology across the reviewed studies, clear and standardised definitions of sub-functionalities were developed to enhance conceptual clarity and differentiation.

Table A2. Operational definitions of packaging sub-functionalities (inductively defined based on the analysis of the reviewed papers)

Packaging functionality	Packaging sub-functionality (enhanced by SP)	Definition
Communication	Information management and accessibility (CM1)	Enhancing the efficient flow of information among supply chain stakeholders using smart indicators, sensors, and data carriers to enable the storage, monitoring, tracking, tracing, and sharing of real-time product data (e.g. Kabadurmus *et al.*, 2023; Rajan and Wani, 2025)
	Information-based decision-making (CM2)	Utilising real-time data to support decision-making and enable informed, proactive, and timely strategic responses (e.g. Abekoon *et al.*, 2024; Heising *et al.*, 2017)
Protection	Preservation (PT1)	Maintaining product quality, freshness, and safety by mitigating spoilage through the controlled release or absorption of active components and the regulation of internal atmospheric conditions (e.g. Zuo *et al.*, 2022; Zhang *et al.*, 2025)
	Environment monitoring (PT2)	Employing sensors, indicators, and data carriers to monitor internal and external environmental conditions and product quality parameters to prevent damage and contamination (e.g. Versino *et al.*, 2023; Kamau *et al.*, 2025)
	Anti-theft (PT3)	Preventing unauthorised removal or loss of products by employing additional security measures to actively safeguard goods during transit, storage, and retail display (e.g. Yang *et al.*, 2024; Fernandez *et al.*, 2023)
	Authentication (PT4)	Verifying product genuineness and preventing the entry of counterfeit items into the supply chain through the integration of embedded identification and tracking mechanisms (e.g. Ahmed *et al.*, 2018; Versino *et al.*, 2023)
	Anti-tampering (PT5)	Providing clear evidence of external environmental impacts to indicate potential product interference, and signalling possible safety or integrity issues (e.g. Mostaccio *et al.*, 2023; Ganeson *et al.*, 2023)
	Traceability (PT6)	Providing information on origin, handling, and movement across the supply chain to ensure transparency, visibility, and integrity while preventing fraud and counterfeiting (e.g. Yang *et al.*, 2024; Singh *et al.*, 2025)

(*continued*)

Table A2. Continued

Packaging functionality	Packaging sub-functionality (enhanced by SP)	Definition
Convenience	Automation and the elimination of manual processes (CV1)	Elevating continuous streams of real-time data collection through data carriers and smart sensors to facilitate data sharing and immediate advanced analysis, resulting in automated data-driven decision-making and process execution (e.g. Abekoon *et al.*, 2024; Htun *et al.*, 2023)
	Process efficiency and optimisation (CV2)	Enhancing the efficiency and optimisation of logistics handling through real-time data from embedded sensors, leading to reduced consumption of resources such as time, energy, materials, and cost (e.g. Gerrans *et al.*, 2023; Mostaccio *et al.*, 2023)
	Streamlined processes (CV3)	Simplifying operations and removing unnecessary steps or redundancies to make processes smoother, quicker, and easier to manage (e.g. Abekoon *et al.*, 2024; Zhang *et al.*, 2025)
	Instructions and recommendations (CV4)	Providing stakeholders with actionable operational guidance (e.g. handling and storage conditions) to enhance information sharing, flow, and timely communication (e.g. Kabadurmus *et al.*, 2023; Al-Thani *et al.*, 2025)
Containment	Enhancing the containability of secondary or tertiary packaging (CT1)	Ensuring the reusability of structurally sound units through condition monitoring and the removal of damaged items, thereby reducing risks during transit and storage (e.g. Machiels *et al.*, 2021; Abekoon *et al.*, 2024)

Source(s): Authors' own elaboration

Supplementary material

The supplementary material for this article can be found online.

References

Abekoon, T., Buthpitiya, B., Sajindra, H., Samarakoon, E., Jayakody, J., Kantamaneni, K. and Rathnayake, U. (2024), "A comprehensive review to evaluate the synergy of intelligent food packaging with modern food technology and artificial intelligence field", *Discover Sustainability*, Vol. 5 No. 1, p. 160, doi: 10.1007/s43621-024-00371-7.

Aguiar, M.L., Gaspar, P.D., Silva, P.D., Domingues, L.C. and Silva, D.M. (2022), "Real-time temperature and humidity measurements during the short-range distribution of perishable food products as a tool for supply-chain energy improvements", *Processes*, Vol. 10 No. 11, p. 2286, doi: 10.3390/pr10112286.

Ahmed, I., Lin, H., Zou, L., Li, Z., Brody, A.L., Qazi, I.M., Lv, L., Pavase, T.R., Khan, M.U., Khan, S. and Sun, L. (2018), "An overview of smart packaging technologies for monitoring safety and quality of meat and meat products", *Packaging Technology and Science*, Vol. 31 No. 7, pp. 449-471, doi: 10.1002/pts.2380.

Al-Thani, M., Hadid, M., Padmanabhan, R., Kerbache, L. and Elomri, A. (2025), "Smart food supply chain management: a bibliometric and systematic review", *Food and Humanity*, Vol. 5, 100736, doi: 10.1016/j.foohum.2025.100736.

Alam, A.U., Rathi, P., Beshai, H., Sarabha, G.K. and Deen, M.J. (2021), "Fruit quality monitoring with smart packaging", *Sensors*, Vol. 21 No. 4, p. 1509, doi: 10.3390/s21041509.

Alves, J., Gaspar, P.D., Lima, T.M. and Silva, P.D. (2023), “What is the role of active packaging in the future of food sustainability? A systematic review”, *Journal of the Science of Food and Agriculture*, Vol. 103 No. 3, pp. 1004-1020, doi: 10.1002/jsfa.11880.

Barone, A.S., Matheus, J.R.V., de Souza, T.S.P., Moreira, R.F.A. and Fai, A.E.C. (2021), “Green-based active packaging: opportunities beyond COVID-19, food applications, and perspectives in circular economy – a brief review”, *Comprehensive Reviews in Food Science and Food Safety*, Vol. 20 No. 5, pp. 4881-4905, doi: 10.1111/1541-4337.12812.

Batista, L., Bourlakis, M., Smart, P. and Maull, R. (2018), “In search of a circular supply chain archetype–a content-analysis-based literature review”, *Production Planning and Control*, Vol. 29 No. 6, pp. 438-451, doi: 10.1080/09537287.2017.1343502.

Beske, P. (2012), “Dynamic capabilities and sustainable supply chain management”, *International Journal of Physical Distribution and Logistics Management*, Vol. 42 No. 4, pp. 372-387, doi: 10.1108/09600031211231344.

Butuc, O., Akkerman, R. and De Leeuw, S. (2025), “Smart packaging adoption in fresh fruits and vegetables supply chains”, *International Journal of Logistics Management*, Vol. 36 No. 7, pp. 284-307, doi: 10.1108/ijlm-08-2024-0521.

Carlos, R.L. and de Mattos, C.A. (2025), “Blockchain-enabled integration of circular economy practices in supply chains: a conceptual framework”, *Business Strategy and Development*, Vol. 8 No. 3, e70222, doi: 10.1002/bsd2.70222.

Chen, S., Brahma, S., Mackay, J., Cao, C. and Aliakbarian, B. (2020), “The role of smart packaging system in food supply chain”, *Journal of Food Science*, Vol. 85 No. 3, pp. 517-525, doi: 10.1111/1750-3841.15046.

da Silva Ponciano, C., Gonzaga, F.C. and de Oliveira, C.P. (2025), “Smart packaging based on chitosan acting as indicators of changes in food: a technological prospecting review”, *International Journal of Biological Macromolecules*, Vol. 319, 145722, doi: 10.1016/j.ijbiomac.2025.145722.

Davidescu, M.A., Pânzaru, C., Mădescu, B.M., Poroşnicu, I., Simeanu, C., Usturoi, A., Matei, M. and Doliş, M.G. (2025), “Advances and challenges in smart packaging technologies for the food industry: trends, applications, and sustainability considerations”, *Foods*, Vol. 14 No. 24, p. 4347, doi: 10.3390/foods14244347.

de Lima, F.A. and Seuring, S. (2023), “A Delphi study examining risk and uncertainty management in circular supply chains”, *International Journal of Production Economics*, Vol. 258, 108810, doi: 10.1016/j.ijpe.2023.108810.

de Lima, F.A., Seuring, S. and Sauer, P.C. (2022), “A systematic literature review exploring uncertainty management and sustainability outcomes in circular supply chains”, *International Journal of Production Research*, Vol. 60 No. 19, pp. 6013-6046, doi: 10.1080/00207543.2021.1976859.

Dev, N.K., Shankar, R., Zacharia, Z.G. and Swami, S. (2021), “Supply chain resilience for managing the ripple effect in Industry 4.0 for green product diffusion”, *International Journal of Physical Distribution and Logistics Management*, Vol. 51 No. 8, pp. 897-930, doi: 10.1108/ijpdlm-04-2020-0120.

Dodero, A., Escher, A., Bertucci, S., Castellano, M. and Lova, P. (2021), “Intelligent packaging for real-time monitoring of food-quality: current and future developments”, *Applied Sciences*, Vol. 11 No. 8, p. 3532, doi: 10.3390/app11083532.

Du, L., Huang, X., Li, Z., Qin, Z., Zhang, N., Zhai, X., Shi, J., Zhang, J., Shen, T., Zhang, R. and Wang, Y. (2025), “Application of smart packaging in fruit and vegetable preservation: a review”, *Foods*, Vol. 14 No. 3, p. 447, doi: 10.3390/foods14030447.

Durach, C.F., Kembro, J. and Wieland, A. (2017), “A new paradigm for systematic literature reviews in supply chain management”, *Journal of Supply Chain Management*, Vol. 53 No. 4, pp. 67-85, doi: 10.1111/jscm.12145.

Endara, P., Wiedmann, M. and Adalja, A. (2023), “Consumer willingness to pay for shelf life of high-temperature, short-time-pasteurized fluid milk: implications for smart labeling and food waste reduction”, *Journal of Dairy Science*, Vol. 106 No. 9, pp. 5940-5957, doi: 10.3168/jds.2022-22968.

Fatorachian, H. and Kazemi, H. (2021), "Impact of Industry 4.0 on supply chain performance", *Production Planning and Control*, Vol. 32 No. 1, pp. 63-81, doi: 10.1080/09537287.2020.1712487.

Fernandez, C.M., Alves, J., Gaspar, P.D. and Lima, T.M. (2021), "Fostering awareness on environmentally sustainable technological solutions for the post-harvest food supply chain", *Processes*, Vol. 9, p. 1611, doi: 10.3390/pr9091611.

Fernandez, C.M., Alves, J., Gaspar, P.D., Lima, T.M. and Silva, P.D. (2023), "Innovative processes in smart packaging. A systematic review", *Journal of the Science of Food and Agriculture*, Vol. 103 No. 3, pp. 986-1003, doi: 10.1002/jsfa.11863.

Firouz, M.S., Mohi-Alden, K. and Omid, M. (2021), "A critical review on intelligent and active packaging in the food industry: research and development", *Food Research International*, Vol. 141, 110113, doi: 10.1016/j.foodres.2021.110113.

Ganeson, K., Mouriya, G.K., Bhubalan, K., Razifah, M.R., Jasmine, R., Sowmiya, S., Amirul, A.A.A., Vigneswari, S. and Ramakrishna, S. (2023), "Smart packaging- a pragmatic solution to approach sustainable food waste management", *Food Packaging and Shelf Life*, Vol. 36, 101044, doi: 10.1016/j.fpsl.2023.101044.

Gatenholm, G., Halldórsson, Á. and Bäckstrand, J. (2021), "Enhanced circularity in aftermarkets: logistics trade-offs", *International Journal of Physical Distribution and Logistics Management*, Vol. 51 No. 9, pp. 999-1021, doi: 10.1108/ijpdlm-11-2020-0367.

Gerrans, J., Donyai, P., Finlay, K. and Sherratt, R.S. (2023), "An efficient smart pharmaceutical packaging technology framework to assess the quality of returned medication through non-intrusively recording storage conditions after dispensation", *Technologies*, Vol. 11 No. 3, p. 75, doi: 10.3390/technologies11030075.

Gligor, D.M. and Holcomb, M.C. (2014), "Antecedents and consequences of integrating logistics capabilities across the supply chain", *Transportation Journal*, Vol. 53 No. 2, pp. 211-234, doi: 10.5325/transportationj.53.2.0211.

Heising, J.K., Claassen, G. and Dekker, M. (2017), "Options for reducing food waste by quality-controlled logistics using intelligent packaging along the supply chain", *Food Additives and Contaminants: Part A*, Vol. 34 No. 10, pp. 1672-1680, doi: 10.1080/19440049.2017.1315776.

Htun, N.N., Wiśniewska, A., Nocella, G., Santa Cruz, E., Peracaula-Moner, A., Vehmas, K., Hakola, L., Liczmańska-Kopcewicz, K., Bridgett, L. and Verbert, K. (2023), "Smart tag packaging technologies: a qualitative investigation of consumers' needs and expectations", *Packaging Technology and Science*, Vol. 36 No. 7, pp. 595-613, doi: 10.1002/pts.2731.

Jayarathna, C.P., Agdas, D. and Dawes, L. (2024), "Perceived relationship between green logistics practices and sustainability performance: a multi-methodology approach", *International Journal of Logistics Management*, Vol. 35 No. 5, pp. 1522-1548, doi: 10.1108/ijlm-09-2022-0367.

Jegen, P., Gast, L. and Faulstich, M. (2025), "A review of the implementation of R-imperatives in circular construction", *Cleaner Production Letters*, Vol. 8, 100097, doi: 10.1016/j.clpl.2025.100097.

Jia, Z., Hou, H., Chen, H., Fu, Y., Mu, W., Yang, X. and Zhang, J. (2025), "From passive to self-aware packs: flexible sensor-AI integration powering intelligent, sustainable food packaging", *Trends in Food Science and Technology*, Vol. 164, 105254, doi: 10.1016/j.tifs.2025.105254.

Kabadurmus, O., Kayikci, Y., Demir, S. and Koc, B. (2023), "A data-driven decision support system with smart packaging in grocery store supply chains during outbreaks", *Socio-Economic Planning Sciences*, Vol. 85, 101417, doi: 10.1016/j.seps.2022.101417.

Kamau, P.G., Cruz-Romero, M.C., Alzate, P.C., Morris, M.A. and Kerry, J.P. (2025), "Active packaging containing natural antimicrobials as a potential and innovative technology to extend shelf-life of fish products–A review", *Food Packaging and Shelf Life*, Vol. 49, 101500, doi: 10.1016/j.fpsl.2025.101500.

Kamboj, A., Kaur, G., Jain, H. and Singh, L. (2025), "The role of smart packaging and consumer psychology in reducing food waste: a review", *Food and Humanity*, Vol. 5, 100826, doi: 10.1016/j.foohum.2025.100826.

Kembro, J., Kunisch, S. and Durach, C.F. (2025), “Why review papers get rejected: common pitfalls and how to avoid them”, *International Journal of Physical Distribution and Logistics Management*, Vol. 55 No. 11, pp. 163-192, doi: 10.1108/ijpdlm-03-2025-0125.

Khan, K.S., Kunz, R., Kleijnen, J. and Antes, G. (2003), “Five steps to conducting a systematic review”, *Journal of the Royal Society of Medicine*, Vol. 96 No. 3, pp. 118-121, doi: 10.1177/014107680309600304.

Kirchherr, J., Reike, D. and Hekkert, M. (2017), “Conceptualizing the circular economy: an analysis of 114 definitions”, *Resources, Conservation and Recycling*, Vol. 127, pp. 221-232, doi: 10.1016/j.resconrec.2017.09.005.

Lu, S.H., Raj, R., Mahajan, A., Jha, A., Verma, P., Lan, H.P. and Singh, S. (2025), “Rethinking and redesigning storage, packaging and distribution practices for food supply chain”, *British Food Journal*, Vol. 127 No. 5, pp. 1648-1675, doi: 10.1108/bfj-03-2024-0286.

Lydekaityte, J. and Tambo, T. (2020), “Smart packaging: definitions, models and packaging as an intermediator between digital and physical product management”, *International Review of Retail Distribution and Consumer Research*, Vol. 30 No. 4, pp. 377-410, doi: 10.1080/09593969.2020.1724555.

Machiels, J., Appeltans, R., Bauer, D.K., Segers, E., Henckens, Z., Van Rompaey, W., Adons, D., Peeters, R., Geißler, M., Kuehnoel, K., Tempel, L., Weissbach, T., Hübler, A.C., Verma, A., Ferraris, E., Deferme, W. and Buntinx, M. (2021), “Screen printed antennas on fiber-based substrates for sustainable HF RFID assisted e-fulfilment smart packaging”, *Materials*, Vol. 14 No. 19, p. 5500, doi: 10.3390/ma14195500.

Mandal, S., Sarathy, R., Korasiga, V.R., Bhattacharya, S. and Dastidar, S.G. (2016), “Achieving supply chain resilience: the contribution of logistics and supply chain capabilities”, *International Journal of Disaster Resilience in the Built Environment*, Vol. 7 No. 5, pp. 544-562, doi: 10.1108/ijdrbe-04-2016-0010.

Mandal, S., Bhattacharya, S., Korasiga, V.R. and Sarathy, R. (2017), “The dominant influence of logistics capabilities on integration: empirical evidence from supply chain resilience”, *International Journal of Disaster Resilience in the Built Environment*, Vol. 8 No. 4, pp. 357-374, doi: 10.1108/ijdrbe-05-2016-0019.

Matan, N., Promwee, A. and Matan, N. (2024), “Active cardboard box with palm wood waste powder and orange oil to prevent browning and quality loss in cabbage: mode of action and potential for reuse”, *Journal of Food Science*, Vol. 89 No. 12, pp. 8539-8554, doi: 10.1111/1750-3841.17493.

Mentzer, J.T., Min, S. and Michelle Bobbitt, L. (2004), “Toward a unified theory of logistics”, *International Journal of Physical Distribution and Logistics Management*, Vol. 34 No. 8, pp. 606-627, doi: 10.1108/09600030410557758.

Mesci, M., Yetkin, N.A. and Pekerşen, Y. (2024), “The impact of technology on food waste: smart packaging”, *Akademik Gıda, (Yeşil Dönüşüm Özel Sayısı)*, No. Yeşil Dönüşüm Özel Sayısı, pp. 51-56, doi: 10.24323/akademik-gida.1554448.

Mohebi, E. and Marquez, L. (2015), “Intelligent packaging in meat industry: an overview of existing solutions”, *Journal of Food Science and Technology*, Vol. 52 No. 7, pp. 3947-3964, doi: 10.1007/s13197-014-1588-z.

Morgan, T.R., Richey, R.G., Jr and Autry, C.W. (2016), “Developing a reverse logistics competency: the influence of collaboration and information technology”, *International Journal of Physical Distribution and Logistics Management*, Vol. 46 No. 3, pp. 293-315, doi: 10.1108/ijpdlm-05-2014-0124.

Mostaccio, A., Bianco, G.M., Marrocco, G. and Occhiuzzi, C. (2023), “RFID technology for food industry 4.0: a review of solutions and applications”, *IEEE Journal of Radio Frequency Identification*, Vol. 7, pp. 145-157, doi: 10.1109/jrfid.2023.3278722.

Mostafayi Darmian, S., Sgarbossa, F., Welo, T. and Dolgui, A. (2026), “Integrating R-imperatives, product development, and supply chain design and planning for sustainability and resilience”, *International Journal of Production Research*, pp. 1-26, doi: 10.1080/00207543.2026.2629363.

Palazzo, M., Vollero, A. and Siano, A. (2023), "Intelligent packaging in the transition from linear to circular economy: driving research in practice", *Journal of Cleaner Production*, Vol. 388, 135984, doi: 10.1016/j.jclepro.2023.135984.

Perotti, S., Cannava, L., Ries, J.M. and Grosse, E.H. (2025), "Reviewing and conceptualising the role of 4.0 technologies for sustainable warehousing", *International Journal of Production Research*, Vol. 63 No. 6, pp. 2305-2337, doi: 10.1080/00207543.2024.2396015.

Potting, J., Hekkert, M.P., Worrell, E. and Hanemaaijer, A. (2017), *Circular Economy: Measuring Innovation in the Product Chain*, PBL Netherlands Environmental Assessment Agency, The Hague.

Rajaguru, R., Matanda, M.J. and Zhang, W. (2022), "Supply chain finance in enhancing supply-oriented and demand-oriented performance capabilities – moderating role of perceived partner opportunism", *Journal of Business and Industrial Marketing*, Vol. 37 No. 7, pp. 1400-1413, doi: 10.1108/jbim-11-2020-0487.

Rajan, S.S. and Wani, K.M. (2025), "A review of smart food and packaging technologies: revolutionizing nutrition and sustainability", *Food and Humanity*, Vol. 4, 100593, doi: 10.1016/j.foohum.2025.100593.

Riggs, R., Roldán, J.L., Real, J.C. and Felipe, C.M. (2023), "Opening the black box of big data sustainable value creation: the mediating role of supply chain management capabilities and circular economy practices", *International Journal of Physical Distribution and Logistics Management*, Vol. 53 Nos 7/8, pp. 762-788, doi: 10.1108/ijpdlm-03-2022-0098.

Robertson, G.L. (2016), *Food Packaging: Principles and Practice*, 3rd ed., CRC Press, Boca Raton.

Sadeghi, K., Kim, J. and Seo, J. (2022), "Packaging 4.0: the threshold of an intelligent approach", *Comprehensive Reviews in Food Science and Food Safety*, Vol. 21 No. 3, pp. 2615-2638, doi: 10.1111/1541-4337.12932.

Sandberg, E. and Abrahamsson, M. (2011), "Logistics capabilities for sustainable competitive advantage", *International Journal of Logistics Research and Applications*, Vol. 14 No. 1, pp. 61-75, doi: 10.1080/13675567.2010.551110.

Semunab, S.N., Zulkifli, C.Z., Ibrahim, A.B. and Noor, N.M. (2016), "Implementation of wireless mobile RFID reader in real world industry environment", *Jurnal Teknologi*, Vol. 78 Nos 5-10, pp. 74-82, doi: 10.11113/jt.v78.8838.

Seuring, S., Yawar, S.A., Land, A., Khalid, R.U. and Sauer, P.C. (2020), "The application of theory in literature reviews – illustrated with examples from supply chain management", *International Journal of Operations and Production Management*, Vol. 41, pp. 1-20, doi: 10.1108/ijopm-04-2020-0247.

Sharma, A., Ranjit, R., Kumar, N., Kumar, M. and Giri, B.S. (2023), "Nanoparticles based nanosensors: principles and their applications in active packaging for food quality and safety detection", *Biochemical Engineering Journal*, Vol. 193, 108861, doi: 10.1016/j.bej.2023.108861.

Singh, A., Prasad, S., Singh, R., Younis, K. and Yousuf, O. (2025), "Revolutionizing the supply chain: cutting-edge strategies and technologies for food waste reduction", *Bioresource Technology Reports*, Vol. 29, 102047, doi: 10.1016/j.biteb.2025.102047.

Taoukis, P. (2010), "Commercialization of time-temperature integrators for foods", in Doona, C.J., Kustin, K. and Feeherry, F.E. (Eds.), *Case Studies in Novel Food Processing Technologies*, Woodhead Publishing, Salt Lake City, pp. 351-366.

Teece, D.J. (2007), "Explicating dynamic capabilities: the nature and microfoundations of (sustainable) enterprise performance", *Strategic Management Journal*, Vol. 28 No. 13, pp. 1319-1350, doi: 10.1002/smj.640.

Tranfield, D., Denyer, D. and Smart, P. (2003), "Towards a methodology for developing evidence-informed management knowledge by means of systematic review", *British Journal of Management*, Vol. 14 No. 3, pp. 207-222, doi: 10.1111/1467-8551.00375.

Upadhyay, A., Agbesi, P., Arafat, K.M.Y., Urdaneta, F., Dey, M., Basak, M., Hong, S., Umeileka, C. and Argyropoulos, D. (2024), "Bio-based smart packaging: fundamentals and functions in sustainable food systems”, *Trends in Food Science and Technology*, Vol. 145, 104369, doi: 10.1016/j.tifs.2024.104369.

Uysal-Unalan, I., Sogut, E., Realini, C.E., Cakmak, H., Oz, E., Espinosa, E., Morcillo-Martín, R., Oz, F., Nurmi, M., Cerqueira, M.A., Perera, K.Y., Ayhan, Z., Arserim-Ucar, D.K., Kanakaki, C., Chrysochou, P., Marcos, B. and Corredig, M. (2024), “Bioplastic packaging for fresh meat and fish: current status and future direction on mitigating food and packaging waste”, *Trends in Food Science and Technology*, Vol. 152, 104660, doi: 10.1016/j.tifs.2024.104660.

Vanderroost, M., Ragaert, P., Devlieghere, F. and De Meulenaer, B. (2014), “Intelligent food packaging: the next generation”, *Trends in Food Science and Technology*, Vol. 39 No. 1, pp. 47-62, doi: 10.1016/j.tifs.2014.06.009.

Versino, F., Ortega, F., Monroy, Y., Rivero, S., López, O.V. and García, M.A. (2023), “Sustainable and bio-based food packaging: a review on past and current design innovations”, *Foods*, Vol. 12 No. 5, p. 1057, doi: 10.3390/foods12051057.

Wang, L., Wu, Z. and Cao, C. (2019), “Technologies and fabrication of intelligent packaging for perishable products”, *Applied Sciences*, Vol. 9 No. 22, p. 4858, doi: 10.3390/app9224858.

Yang, Y., Du, Y., Gupta, V.K., Ahmad, F., Amiri, H., Pan, J., Aghbashlo, M., Tabatabaei, M. and Rajaei, A. (2024), “Exploring blockchain and artificial intelligence in intelligent packaging to combat food fraud: a comprehensive review”, *Food Packaging and Shelf Life*, Vol. 43, 101287, doi: 10.1016/j.fpsl.2024.101287.

Young, E., Mirosa, M. and Bremer, P. (2023), “A conceptual model for food industry views on the commercialisation of active and intelligent packaging”, *Packaging Technology and Science*, Vol. 36 No. 11, pp. 905-925, doi: 10.1002/pts.2766.

Zhang, J., Zhang, J., Zhang, L., Qin, Z. and Wang, T. (2025), “Review of recent advances in intelligent and antibacterial packaging for meat quality and safety”, *Foods*, Vol. 14 No. 7, p. 1157, doi: 10.3390/foods14071157.

Zuo, J., Feng, J., Gameiro, M.G., Tian, Y., Liang, J., Wang, Y., Ding, J. and He, Q. (2022), “RFID-based sensing in smart packaging for food applications: a review”, *Future Foods*, Vol. 6, 100198, doi: 10.1016/j.fufo.2022.100198.

Corresponding author
Promporn Wangwacharakul can be contacted at: promporn.wangwacharakul@liu.se