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Manufacturing SMEs Leveraging a Progressive Model for Circular Economy Capability Development to Catalyse Sustainable Commitment

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This study theorizes the developmental process of circular economy (CE) capabilities in manufacturing small- and medium-sized enterprises (SMEs), with a particular emphasis on aligning these efforts with the pursuit of net-zero targets. Drawing on dynamic capability theory (DCT) and employing a comparative longitudinal case study approach, we propose a progressive, three-stage model that encompasses cognitive realignment, structural reconfiguration and institutionalized evolution. Our findings reveal that, rather than representing linear or static transitions, each stage constitutes a dynamic, iterative process through which SMEs continuously adapt and refine their CE capabilities in response to changing environmental, market and regulatory demands. Furthermore, the findings demonstrate a strong alignment with the core dimensions of DCT, sensing, seizing and transforming, offering a robust theoretical lens to understand how SMEs systematically develop and operationalize CE capabilities to support their net-zero ambitions. This integration provides new insights into the interplay between dynamic capabilities and sustainability, advancing both theoretical and practical understanding of CE capability development within the manufacturing sector.

Introduction

The circular economy (CE) is a regenerative economic model that addresses sustainability challenges by transitioning from the traditional linear 'take, make, dispose' approach to circular processes. CE focuses on minimizing waste and maximizing resource regeneration across production, consumption and disposal phases (Kamal *et al.*, 2022; Priyadarshini *et al.*, 2022). Its adoption has become critical for achieving long-term sustainability in business operations, as global policy directives, such as the United Nations' sustainable development goals, emphasize resource efficiency, emission reduction and waste management (Ellen MacArthur Foundation, 2021). By fostering a 'sustainable culture', businesses can improve performance and resilience (Huo, Gu and Wang, 2019). However, transitioning to CE is particularly difficult for small- and medium-sized enterprises (SMEs), particularly in the technology manufacturing sector, due to resource constraints, limited expertise and insufficient access to CE knowledge (Alraja *et al.*, 2022).

Existing research on CE capabilities has made important contributions to understanding the principles and benefits of CE. The literature can be categorized into three areas: conceptualization, which defines CE capability and provides theoretical foundations (e.g. Bag *et al.*, 2021; Kusumowardani *et al.*, 2022); measurement, which develops scales and metrics to assess CE capabilities (e.g. Zeng *et al.*, 2017); and organizational impact, which examines the effects of CE capabilities on firm performance and sustainability outcomes (e.g. Bag *et al.*, 2022; de Arroyabe *et al.*, 2021).

While valuable, these studies have theoretical limitations that hinder the field's advancement. First, much of the research adopts a static perspective, focusing on the benefits of CE capabilities rather than the dynamic and iterative processes through which these capabilities are developed and refined. This overlooks the complexity of capability formation, particularly in SMEs that must adapt to resource constraints and evolving pressures. Second, existing studies emphasize the importance of resources but often ignore how firms reconfigure and redeploy them to build CE capabilities. Resource-constrained SMEs cannot rely solely on resource accumulation; they must dynamically realign operations with CE principles. Third, most studies neglect how CE capabilities evolve over time in response to internal and external changes. CE adoption is an ongoing process requiring firms to sense opportunities, seize them and adapt their operations. Treating CE capability as a fixed construct fails to capture its temporal and evolutionary aspects, which is particularly problematic for SMEs facing uncertainties and requiring flexible strategies to transition to CE practices.

Addressing these theoretical gaps, this study investigates a pivotal research question: *How do technology manufacturing SMEs develop CE capabilities*? By conducting a longitudinal analysis of six manufacturing SMEs, this research moves beyond the static perspectives common in the literature to provide a process-oriented framework for understanding CE capability development. The study captures the iterative, adaptive nature of capability formation, offering new insights into the mechanisms that enable SMEs to overcome resource constraints and align their operations with CE principles.

This study applies dynamic capabilities theory (DCT) to examine how firms adapt to changing environments by sensing opportunities, seizing them and reconfiguring resources (Teece, Pisano and Shuen, 1997). DCT is especially relevant for understanding CE capability development, as it emphasizes dynamic, iterative processes that help SMEs navigate resource constraints, uncertainty and external pressures (Buzzao and Rizzi, 2021). Since CE adoption demands ongoing innovation, operational restructuring and regulatory alignment, DCT effectively captures the evolution of capabilities through sensing waste-reduction opportunities, seizing them via strategic innovation and reconfiguring resources to support sustainable systems (Schilke, Hu and Helfat, 2018). DCT also explains how SMEs gradually build CE capabilities and shift from linear models to sustainable ones in pursuit of net-zero goals (Hernández-Linares, Kellermanns and López-Fernández, 2021).

Based on a longitudinal study of six manufacturing SMEs, this research develops a dynamic process model that captures the evolution of CE capabilities. It makes three key theoretical contributions. First, it shifts the focus of CE capability research to its dynamic and iterative development, particularly for SMEs working toward net-zero targets, addressing a gap in studies that view CE capabilities as static attributes. Second, it strengthens the connection between CE capability development and DCT by integrating core principles like sensing, seizing and transforming to explain how firms systematically develop dynamic capabilities aligned with CE objectives. Third, it provides industry-specific insights into CE capability development within the manufacturing sector, focusing on the unique challenges faced by SMEs.

The paper is structured as follows: after the introduction, we outline the theoretical foundation of the study. Next, we describe the research methodology, including data collection and analysis. This is followed by the findings and a discussion of theoretical implications, practical applications, limitations and future research directions.

Theoretical underpinning

DCT provides a robust framework for understanding how technology-manufacturing SMEs develop CE capabilities to achieve net-zero sustainability goals. While DCT traditionally focuses on an organization's ability to adapt, learn and transform in dynamic environments, this study extends its theoretical utility by operationalizing the core processes of sensing, seizing and transforming specifically in the context of CE transitions. This approach highlights the iterative and processual nature of capability development that underpins the shift from linear to circular business models (Pitelis, Teece and Yang, 2024; Teece, Pisano and Shuen, 1997).

Literature synthesis method

To build a robust theoretical foundation for applying DCT to CE capability development, we conducted a structured synthesis of relevant literature rather than a full systematic literature review, as the focus is on theoretical exploration and case-based theorizing. We searched databases including Scopus, Web of Science and Google Scholar using keywords such as 'circular economy capabilities', 'dynamic capabilities theory', 'SMEs sustainability', 'net-zero manufacturing' and combinations like 'DCT AND circular economy'. The search spanned publications from 2010 to 2024 to capture recent advancements in the field. Inclusion criteria focused on peer-reviewed studies addressing CE in manufacturing contexts, DCT applications to sustainability and SME-specific challenges; exclusions were non-empirical opinion pieces or unrelated sectors (e.g. services). From these, key sources were synthesized to identify gaps (e.g. static vs. dynamic views of CE) and inform our model. This approach ensures a rigorous, literature-informed framework while allowing flexibility for inductive case insights.

Applying DCT to CE capability development

This study explores how the three core processes of DCT, sensing, seizing and transforming, are enacted within the CE context. Dynamic capabilities are understood to emerge from a blend of best practices, widely accepted routines and firm-specific signature practices rooted in proprietary knowledge (Pitelis, Teece and Yang, 2024). While existing CE research often focuses on outcomes such as resource efficiency and waste reduction, the developmental process of CE capabilities, particularly how SMEs integrate best and signature practices, remains underexplored. This study addresses that gap by examining the evolutionary mechanisms behind CE capability formation, offering deeper insight into DCT's application in CE. Sensing involves identifying and interpreting opportunities and threats that guide strategic adaptation (Schilke, Hu and Helfat, 2018); seizing entails mobilizing resources to act on these opportunities, as seen in recyclable material adoption and product redesign (Buzzao and Rizzi, 2021); and transforming refers to reconfiguring structures and processes to embed CE capabilities and align with long-term sustainability goals, including net-zero targets (Zahra, Sapienza and Davidsson, 2006). Collectively, these interconnected processes enable SMEs to build the dynamic capabilities essential for effective CE adoption.

Research method

This study uses a qualitative multiple case study approach, known for its strong theory-building capabilities in complex real-world contexts (Eisenhardt, 1989; Yin, 2003). Focusing on technology-manufacturing SME founders and managers driving CE practices, this design enables a detailed exploration of CE capability development. Through structured and open-ended interviews and document analysis, we examine the evolution of CE capabilities from their inception, offering in-depth insights into this dynamic process.

Research setting

SMEs represent a theoretically important context for exploring the development of CE capabilities essential for achieving net-zero targets. As they comprise over 90% of global businesses, SMEs significantly contribute to industrial waste, emissions and resource depletion, especially in manufacturing, making them key players in sustainability transitions. Their cumulative, incremental improvements can drive meaningful systemic change. From a capability development standpoint, SMEs' flexibility and responsiveness to external pressures like regulatory shifts and market demands allow for iterative experimentation with CE practices. This adaptability offers a valuable lens for understanding how firms build the competencies needed to shift from linear to circular models.

This study focuses on manufacturing SMEs, firms with fewer than 500 employees in technology-driven sectors such as electronics, machinery and automotive. It deliberately excludes multinational corporations (MNCs), which, despite having more resources, often face bureaucratic challenges in executing DCT processes like opportunity seizing. Although supply chain tiers are acknowledged, the analysis centres on the focal SME rather than upstream or downstream partners. This SME-centric approach emphasizes how resource-constrained firms apply DCT to enable CE transitions, offering insights that could be adapted to larger firms or complex supply chains with appropriate adjustments for scale and operational complexity.

The heterogeneity of SMEs in size, resources and sectoral focus makes them a highly relevant research setting. Their diversity allows examination of how organizational contexts shape pathways to CE adoption and capability formation. Despite resource constraints, SMEs are key innovation drivers, particularly in niche markets, where limitations foster creative solutions and novel approaches to CE. These innovations strengthen SME capabilities and offer scalable models for wider adoption, positioning SMEs as catalysts of systemic change. Studying SMEs thus provides valuable insights into how CE capabilities are developed, refined and diffused, enriching our understanding of sustainability transitions at both firm and system levels.

Data collection

Sampling strategy. Our research focused on a carefully selected group of manufacturing SMEs with expertise in CE capability development. Using purposive sampling, we identified 32 potential firms from the Beijing Municipal Science & Technology Commission and Zhongguancun Science Park, narrowing to six through invitations, snowballing and personal connections. Senior managers, including CEOs and sustainability leaders, participated. Firms were selected based on over 5 years of CE integration, long-term commitment to net-zero goals and active engagement in zero-carbon models and demonstration projects. This ensured rigorous examination of the research question. As nationally recognized technology manufacturers, these SMEs combined innovation with alignment to industry standards

Table 1. Sample characteristics

Groups	SMEs	Founding year	Firm location	CE practices history	Manufacturing industries	CE maturity
1	SME A	2003	Beijing	8 years	Computer and Electronics	Expansion (low maturity)
	SME B	2005	Beijing	7 years	Computer and Electronics	Optimization (high)
2	SME C	2007	Beijing	6 years	Machinery and Equipment Manufacturing	Expansion (low)
	SME D	2002	Beijing	9 years	Machinery and Equipment Manufacturing	Leadership (high)
3	SME E	2003	Beijing	10 years	Automotive Manufacturing	Expansion (low)
	SME F	2004	Beijing	8 years	Automotive Manufacturing	Transformation (medium)

and sustainability priorities. The focus on SMEs offered insights into both the adaptability and challenges of CE implementation. This targeted selection provides a representative sample of manufacturing SMEs pursuing sustainability, yielding practical lessons and a nuanced understanding of CE capability development for net-zero transitions.

Our research examined manufacturing SMEs in Zhongguancun, Beijing, 'China's Silicon Valley', an ideal setting for studying CE capabilities given its strong industrial, technological and collaborative ecosystem. The region's concentration of technology-driven enterprises and research institutions fosters innovation and industrial transformation, while its strategic focus on high-tech industries, sustainability and inter-organizational collaboration supports CE development. SMEs benefit from market pressures, supportive policies and technological access, aligning closely with our study's objectives. A uniform regulatory framework also minimizes external variability, providing a controlled environment for analysing CE capability development. Although rooted in Zhongguancun, the findings offer insights relevant to other innovation-driven ecosystems.

From the candidate pool, six firms met the selection criteria and were organized into three industry-specific clusters within the manufacturing sector. This structure enables contextual insights into sectoral challenges and opportunities related to achieving net-zero through CE capabilities, while also supporting comparative analysis across sub-sectors. Sample characteristics are detailed in Table 1.

Interview and data collection. We conducted a qualitative study with 42 interviews of firm leaders to explore CE capability development. The interview protocol was developed, pilot-tested and refined for clarity. Using criterion-based sampling, we selected participants involved in CE initiatives, including CEOs, co-founders and CE managers from six manufacturing firms in Zhongguancun, known for its innovative ecosystem. This captured insights into strategic and operational aspects of CE. To address biases like overly strategic views, questions probed practical challenges, resistance and cross-functional dynamics. Interviews, lasting 60–100 min, were conducted virtually or in person, with open-ended questions about circular practices, CE stages, net-zero goals and successful projects. Informal interviews with senior managers added reflective insights and clarified complex issues like mapping activities. Triangulation with reports and sustainability metrics balanced perspectives and enhanced reliability. This ensured our findings captured strategic and practical realities. Table 2 summarizes the data collection.

Data analysis

We adopted an inductive, exploratory approach to examine how manufacturing SMEs develop CE capabilities, ensuring rigor through systematic steps. Data sources included interviews, archival documents (firm reports, sustainability records) and observational notes, offering a comprehensive view. Archival evidence provided time-sequence insights and was cross-checked with interviews for validity. Researchers manually coded the data for deep engagement, supplemented by NVivo to categorize themes, compare results, refine categories and enhance consistency. Firm reports verified claims, and quantitative metrics confirmed outcomes, strengthening credibility. Data saturation was reached when no new themes emerged. Multiple researchers cross-coded to minimize bias, resolving discrepancies collaboratively. External validation involved sharing findings with firms for feedback, refining interpretations. The analysis followed four stages: initial case analysis, open coding, axial coding and extraction of dimensions.

Step 1: Initial case analysis. The analysis began with in-depth examination of interviews, archival documents and observational notes to construct chronological narratives for each firm's CE practices. Archival documents were especially valuable, offering longitudinal perspectives on circular initiatives and net-zero commitments, while corroborating and extending interview data with insights into strategic decisions often unspoken by participants. Narratives were then shared with firms for feedback and refinement, ensuring accuracy and mutual validation. This iterative process provided a nuanced understanding of each case and enabled meaningful cross-case comparisons.

Step 2: Open coding process. In this phase, participants' comments were analysed through multiple iterations to generate preliminary codes capturing in-

Table 2. Summary of data sources

Groups	SMEs	Semi-structured interviews			Informal consultations	
CEO	Co-founder	CE practices managers	Informal interviews with CEOs	Informal interviews with CE managers		
1	SME A	2	2	3	2	3
	SME B	2	2	3	2	3
2	SME C	2	2	3	3	4
	SME D	2	2	3	3	5
3	SME E	2	2	3	4	2
	SME F	2	2	3	2	3
In total		12	12	18	16	20
Grand total			42		36	

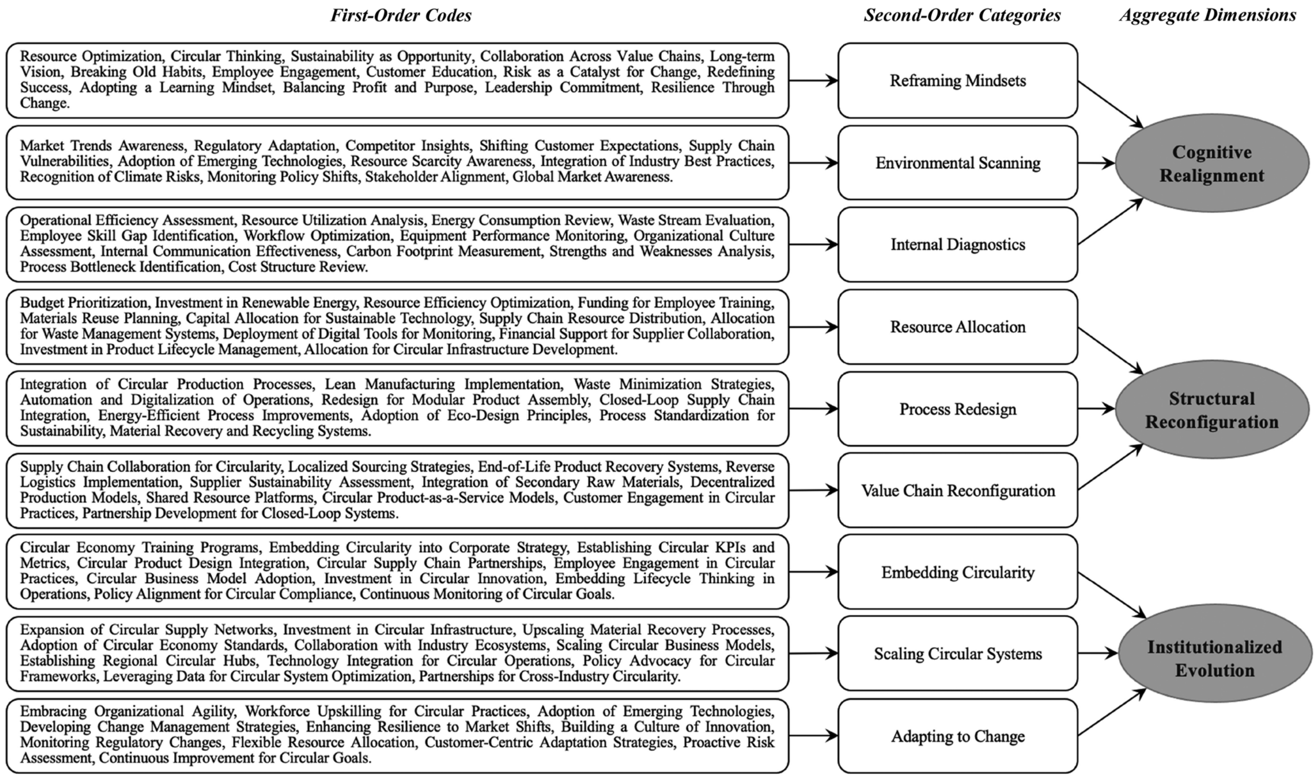

Figure 1. Data structure of stages of CE capability development process

sights from each case. Contributions on CE capability development were transcribed and categorized into concepts such as resource optimization, circular thinking, sustainability as opportunity and adopting a learning mindset (see Figure 1). Codes were reviewed with participants and industry experts, adding diverse perspectives and shaping subsequent analysis. The open coding process identified key mechanisms of CE capability development by comparing cases to highlight commonalities and differences. Patterns were refined into cohesive codes, forming a narrative framework (Figure 1) that accurately reflected the complexity of CE capability building in manufacturing SMEs.

Step 3: From open coding to axial coding. In this phase, preliminary codes were refined into second-order themes to identify broader patterns and relationships. For example, the theme environmental scanning encompassed first-order observations such as market trends awareness, regulatory adaptation, competitor insights, shifting customer expectations, supply chain vulnerabilities, adoption of emerging technologies and resource scarcity awareness (Figures 1–4). Theme development involved reflection and debate to ensure each accurately represented original codes and broader concepts. This validation confirmed coherence and grounded the thematic structure in the data. Figures 1–4 illustrate the alignment between first-order codes and second-order themes, showing the evolution of the analysis.

Step 4: From axial coding to aggregate dimension extraction. In the final stage, the researchers transi-

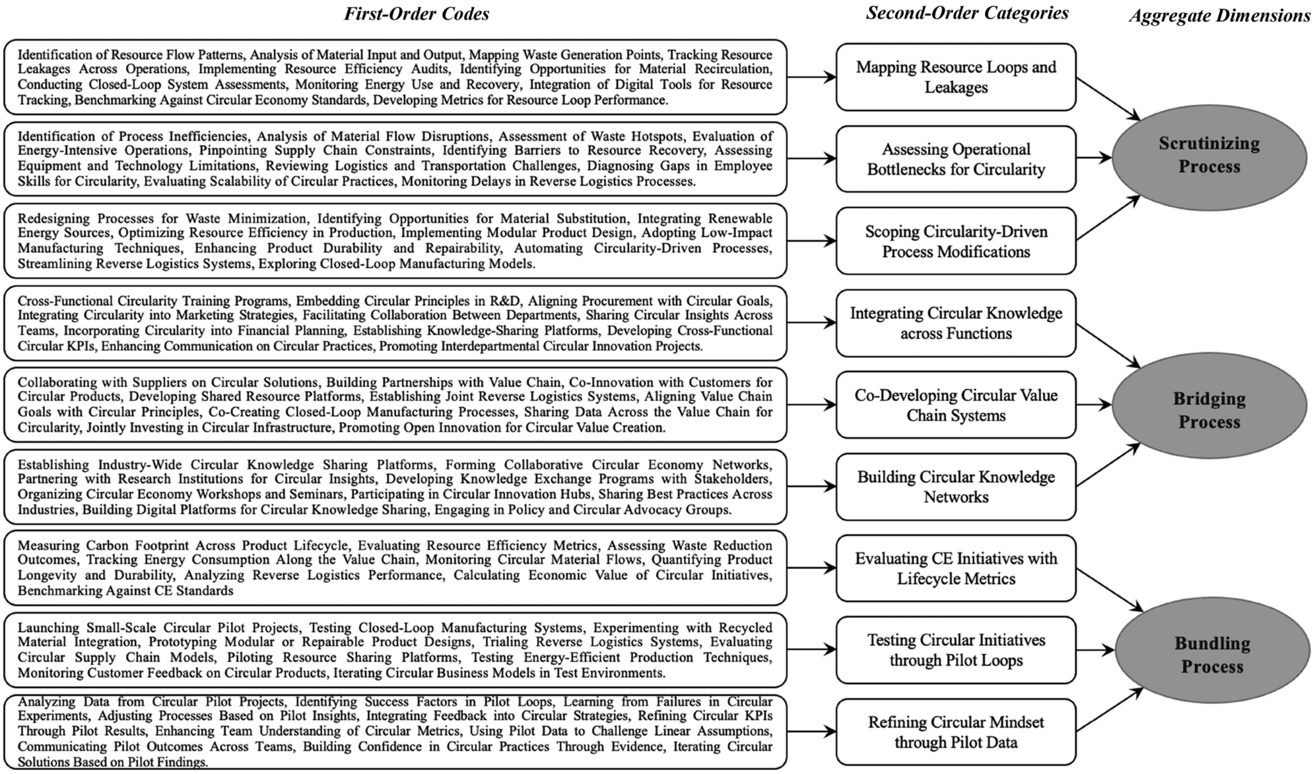

Figure 2. Data structure of the sub-process within the cognitive realignment stage

tioned from second-order themes to develop aggregate dimensions by exploring broader constructs for deeper insights. Comparative analysis examined interrelations between themes and opportunities for integration into higher-order dimensions. For example, themes like 'reframing mindsets', 'environmental scanning' and 'internal diagnostics' were combined into a single dimension called 'cognitive realignment' (see Figure 1). To ensure rigor and relevance, researchers shared the framework with interviewees for feedback, refining it based on their insights.

Figures 1–4 illustrate the progression from codes to themes and aggregate dimensions, offering a clear framework for understanding CE capability development in manufacturing SMEs.

Findings

Progress stages of CE capability development

Our analysis of manufacturing SMEs' journey towards circularity and net-zero targets reveals a structured, multi-stage capability progression. This includes three stages (see Figure 5): cognitive realignment (identifying circular opportunities), structural reconfiguration (implementing circular solutions) and institutionalized evolution (transforming systems). Each stage has distinct, interconnected phases that build CE capability, supporting the shift to circular and net-zero practices.

Stage 1: Cognitive realignment. We see the first stage of CE capability as cognitive realignment, where SMEs recalibrate their frameworks to view sustainability and resource management as strategic priorities instead of mere compliance. This reorientation helps them recognize circular opportunities, for example, like reducing waste and emissions, as paths to innovation and competitiveness, aligning their operations with sustainable practices. Cognitive realignment involves internalizing circularity as a core strategy, enabling SMEs to see environmental challenges as opportunities for transformation. This creates a foundation for deeper engagement with CE principles and ongoing capability development for long-term sustainability. For example, the CEO from SME B illustrated their experience: 'At first, sustainability felt like something we just had to do, ticking a box to meet regulations or to keep others happy. But as we started learning about circular economy principles, we realized it wasn't just about following the rules. It made us rethink how we manage resources and design our processes. Instead of seeing waste and inefficiency as problems, we started looking at them as opportunities, ways to create value and cut down our environmental impact. That change in how we thought about things was a big turning point for us, and it helped us start embedding sustainability into how we do business'.

Cognitive realignment involves three dimensions: reframing mindsets, environmental scanning and internal

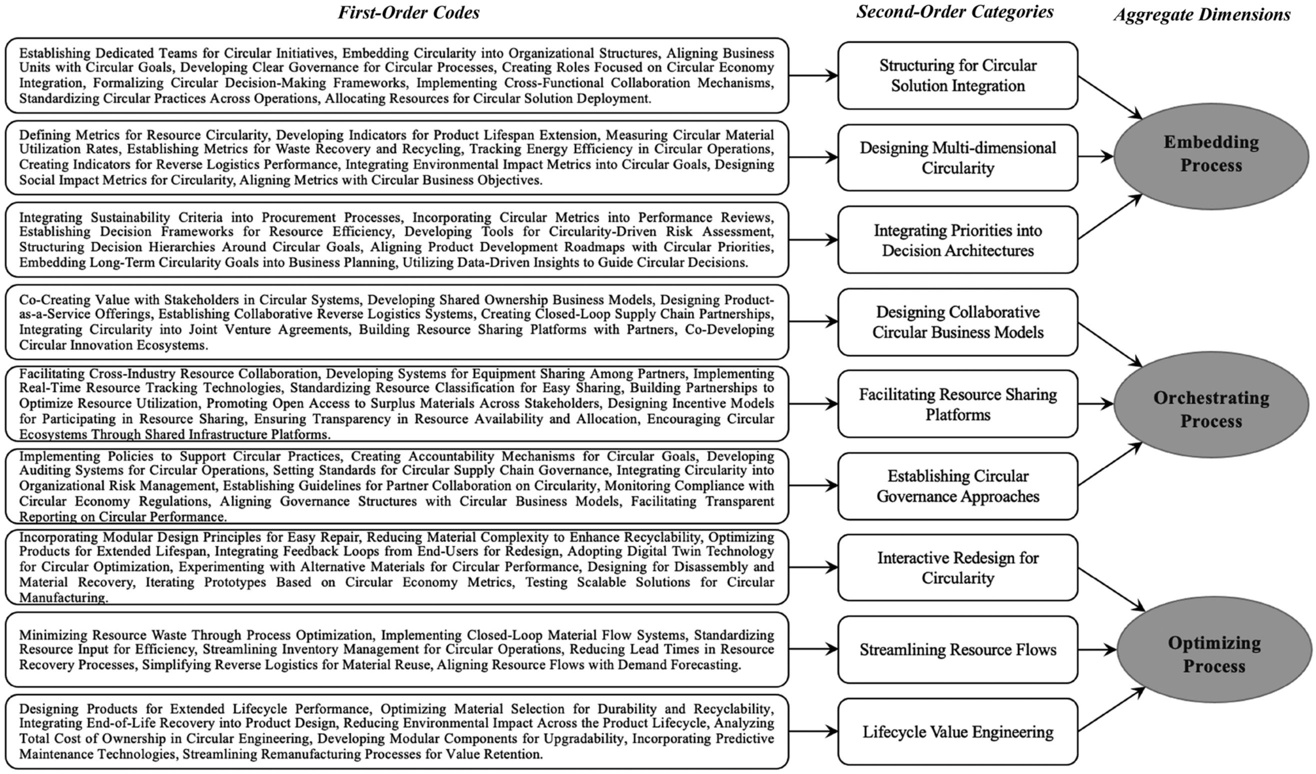

Figure 3. Data structure of the sub-process within the structural reconfiguration stage

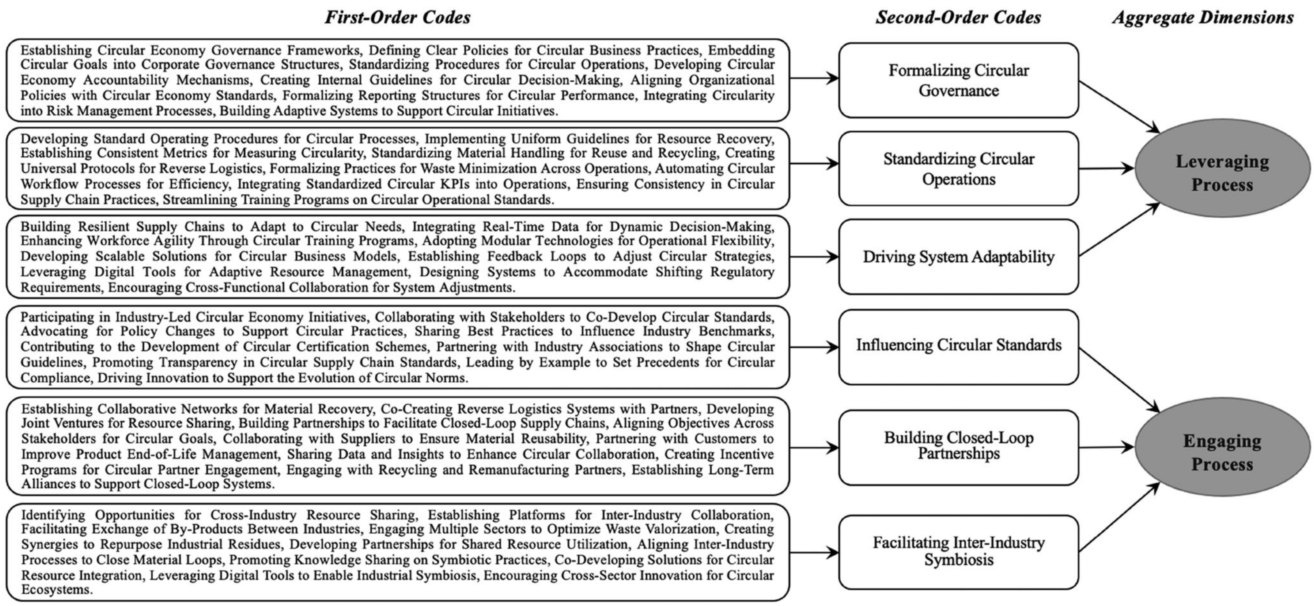

Figure 4. Data structure of the sub-process within the institutionalized evolution stage

diagnostics, forming the basis for developing capabilities in CE transitions. Reframing mindsets reconfigures organizational cognition, replacing assumptions about waste with views that focus on resource optimization, innovation and system renewal. This process internalizes circularity, helping organizations shift from linear to sustainable practices. Reinterpreting inefficiencies as parts of circular systems enables adaptive, regenerative behaviour aligned with CE principles. For example, as one of the co-founders from the SME A explained, 'We used to see waste as just a cost … something we had to get rid of. But now we're asking ourselves, what can this 'waste' actually do for us? Looking at it differently has led us to so many new possibilities'.

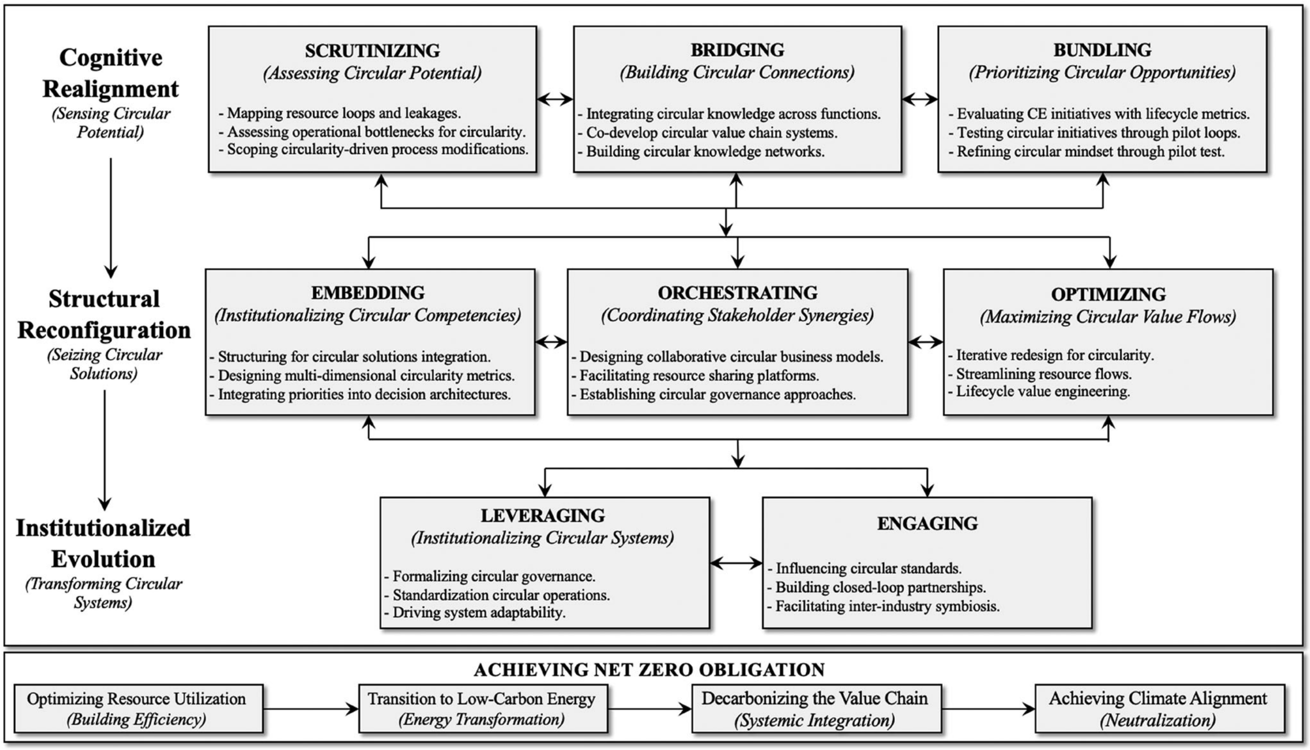

Figure 5. The dynamic process model for CE capability development in manufacturing SME

Environmental scanning is a structured process aimed at analysing external factors that influence organizational decision-making, including regulatory transformations, shifting market dynamics and advancements in technology. This process facilitates the identification of strategic opportunities for integrating circular innovation by aligning external pressures with sustainable operational practices. For instance, the manager from SME B highlighted this point: 'When the new regulations took effect, we realized it wasn't just about meeting requirements. It was a chance to rethink how we could provide more value to our customers while also finding ways to recover materials along the way'.

Internal diagnostics are essential for improving operational sustainability by identifying inefficiencies and processes with significant environmental impacts. Through the use of lifecycle assessments, organizations can systematically map resource flows, pinpoint resource-intensive or emission-heavy activities and develop evidence-based strategies to prioritize interventions and enhance efficiency. For example, the CEO from SME D shared, 'We took a closer look at how we were running things and were shocked to see just how much energy and material we were wasting. It really opened our eyes and showed us where we could make the biggest impact'.

Cognitive realignment is a multidimensional process that reshapes how SMEs perceive and prioritize circularity. By reframing waste and inefficiency, scanning for external opportunities and diagnosing internal challenges, this stage builds the cognitive and strategic foundation for deeper engagement with CE principles.

Stage 2: Structural reconfiguration. The second stage of CE capability development, structural reconfiguration or seizing circular solutions, is defined as the systemic integration of circular principles into core organizational structures, including operations, supply chains and business models. This phase involves reorganizing resource flows and production systems to enable closed-loop processes that emphasize efficiency, waste reduction, carbon mitigation and material regeneration. Achieving this requires both technological adoption and the redesign of production methods and supply chain networks to align with CE goals. As a dynamic capability, structural reconfiguration drives the shift from linear to circular systems through deep, transformative changes rather than incremental tweaks, marking a fundamental evolution in operational practices to advance sustainability transitions. As the CEO of SME D explained:

> To make circularity work, we had to change everything, from how we design our products to how we manage waste and work with our suppliers. It wasn't just about fixing a few issues. It was about creating something sustainable that could actually last. We invested in new equipment, trained our team to use it, and partnered with suppliers to build a system where nothing goes to waste. It was challenging,

> but in the end, we cut costs, recovered materials we used to throw away, and gave our customers more value than ever.

Structural reconfiguration involves three interconnected dimensions: resource allocation, process redesign and value chain reconfiguration. Resource allocation refers to strategically deploying organizational resources like financial, technological and human capital to build capabilities for circular practices. It emphasizes targeted investments in infrastructure, technology and workforce development to embed circularity. For manufacturing SMEs, this includes investing in remanufacturing, additive manufacturing or energy-monitoring tools to optimize resources, reduce waste and align with CE principles. This stage is vital for shifting from linear to closed-loop systems, forming the foundation for further changes. As the manager from SME E indicated, 'We invested in remanufacturing tools to reuse materials from old products and trained our team to use them effectively. It wasn't cheap upfront, but the savings we're seeing now? Completely worth it'.

Process redesign systematically reconfigures workflows to align with CE principles by minimizing waste, enhancing resource recovery and improving energy efficiency. It emphasizes integrating innovative practices like digital tools to enable closed-loop systems, making it vital for embedding circularity and shifting from linear to resource-efficient models. The CEO of SME A shared their experience: 'We reworked our production process to get more out of materials that used to be wasted. It's helped us save money and make a positive impact on the environment, which is something we're genuinely proud of'.

Value chain reconfiguration involves strategically realigning supply networks to implement CE principles, restructuring interactions and processes for closed-loop material flows and resource regeneration. It promotes co-creating circular systems via collaboration with stakeholders like suppliers and customers, integrating secondary materials, establishing take-back systems and designing processes focused on recovery and reuse. This reconfiguration is crucial for systemic circularity, ensuring resource efficiency, waste reduction and sustainable production–consumption. The CEO of SME E highlighted this effort: 'We worked with our suppliers to start using recycled materials and set up a system so customers can return products when they're done with them. It wasn't simple, but it's making a big difference'.

This stage is a theoretical construct that helps businesses move beyond traditional linear models by creating systems to recover and reuse resources, cut emissions and reach net-zero goals. Structural reconfiguration is a key process focusing on system-wide changes and building organizational skills to develop sustainable economic systems.

Stage 3: Institutionalized evolution. The third stage of CE development is institutionalized evolution, marked by systemic change in circular systems within SMEs. CE principles become embedded in governance, strategy and culture. This shift moves from adopting isolated circular practices to making circularity a core organizational element. SMEs continuously adapt their systems to improve scalability, resilience and respond to technological, regulatory and market changes. This evolution involves integrating CE into organizational structure and strategy, supporting long-term net-zero goals and systemic sustainability. As the CEO of SME C illustrated their practices:

> If you want circularity to actually work, you can't treat it like a one-time thing, it has to be part of how your company runs. It's about the way you make decisions, how you operate, and how you think. We made it a core part of our strategy, built a team to lead the charge, and scaled our refurbishment programs around the world. It's not easy, and it doesn't happen overnight, but by making it part of everything we do, we've created something that's built to last and ready to grow with the future.

Institutionalized evolution has three key dimensions: embedding circularity, scaling systems and adapting to change. Embedding circularity means systematically integrating CE principles into governance and strategy, formalizing practices through dedicated teams, committees or boards. It ensures CE becomes part of the organization's structure and strategic goals, aligning with long-term priorities. As their CEO from SME A stated: 'We wanted circularity to be more than just an operational goal. It needed to be part of our leadership conversations and embedded in our long-term plans'.

Scaling circular systems involves standardizing CE practices across organizations and supply chains. It emphasizes creating uniform frameworks to apply circular principles consistently, boosting resource efficiency, reducing waste and optimizing material flows. This supports broader sustainability goals and a shift to a regenerative economy. SME C, for instance, scaled up its product refurbishment programmes globally. Their manager shared: 'For us, circularity couldn't simply be an extra initiative. It needed to be central to how we operate as a business if we were serious about achieving our net-zero goals. This required rethinking our strategy, expanding programmes like product refurbishment on a global scale, and embedding circularity into every decision we make. Today, it has become an integral part of how we work, driving us toward a more sustainable future and ensuring we stay on track to meet our goals'.

Finally, adapting to change is seen as iterative adjustments and evolution of circular systems responding to external factors like technology, regulation and market shifts. It underscores the importance of flexibility and responsiveness in keeping CE practices effective and relevant in dynamic socio-economic and environmental contexts. SME F enhanced its reverse logistics systems to meet stricter recycling standards, with its manager saying: 'We needed to reevaluate how we manage returns and recover materials to comply with new regulations, and it has significantly improved our efficiency'.

Institutionalized evolution involves integrating CE principles into SME governance, strategy and operations. By embedding circularity, scaling systems and adapting, SMEs move from isolated practices to systemic change, fostering scalability, resilience and sustainability. This positions SMEs as catalysts for long-term systemic transformation.

Exploring the core processes within each stage

Within the cognitive realignment stage. Stage 1 constitutes the foundational phase in the development of CE capabilities for manufacturing SMEs, characterized by three interrelated processes: scrutinizing, bridging and bundling.

Scrutinizing: Assessing circular potential. The scrutinizing process is a systematic diagnostic tool that identifies resource inefficiencies, constraints and enablers for circularity. It maps resource loops and leakages, analysing material flows within production. This uncovers inefficiencies, resource dependencies and waste points. These insights form the basis for designing circular strategies aligned with CE principles. The CEO from SME E shared that: 'After analysing our material flows, we discovered that a significant portion of our raw materials was becoming scrap during production. This realization led us to invest in a system to reuse that scrap within the company'.

The second focus, assessing operational bottlenecks for circularity, involves identifying and analysing systemic constraints within production systems that hinder circular practices. These bottlenecks stem from technical, organizational and human limitations, such as outdated technology, rigid production setups and limited workforce skills for circular innovation. Addressing these constraints is essential for enabling systemic changes and aligning production with CE principles. For example, the manager from SME D indicated that: 'Our biggest challenge was clear, the existing equipment was too inflexible to accommodate modular designs. It took approximately six months to determine the necessary changes, and we are now in the process of updating several production lines to address this issue'.

The final focus, scoping circularity-driven process modifications, involves examining and planning incremental changes to existing processes or product designs to align with CE principles. This includes evaluating design tweaks, like improving disassembly, reuse or remanufacturing, to recover resources and reduce waste. These adjustments are key to solving systemic inefficiencies and integrating circularity into production systems. For example, the manager from SME B supported that: 'The turning point for us came when we identified a small adjustment in our product design that allowed us to reuse parts rather than discard them. While it wasn't a significant change, it unlocked numerous opportunities for future circular innovations'.

Bridging: Building circular connections. The bridging process involves creating collaborative mechanisms and network connections to adopt circular practices, both within and between organizations. Internally, it integrates circular knowledge across departments like R&D, procurement and operations, breaking silos to promote knowledge exchange, align goals and support systemic moves towards circularity. For example, the manager from SME F shared that: 'We brought our procurement and R&D teams together for the first time to explore the use of recyclable materials in our products. It was remarkable to see the insights and opportunities that emerged simply by having everyone collaborate in the same space'.

The second focus on co-developing circular value chains involves creating partnerships with suppliers, recyclers and logistics providers. It highlights the importance of inter-organizational collaboration for knowledge exchange, aligning goals and co-creating value chain setups that support CE principles. These systems are key enablers for resource circulation, efficiency and systemic circular practice integration. The CEO from SME D shared with us that: 'We collaborated with a local recycler to establish a take-back system for our used products. This partnership was mutually beneficial, as it allowed us to recover valuable materials while providing them with a new business opportunity'.

The final focus on building circular knowledge networks involves developing inter-organizational exchange frameworks with industry associations, academic institutions and government agencies. It emphasizes leveraging external networks to access expertise, funding and new technologies. These networks are vital for knowledge diffusion, innovation and transitioning to CE practices. For example, the CEO from SME A illustrated: 'Joining an industry group proved to be a transformative step for us. It provided valuable insights into modular design and allowed us to secure funding through a government grant to test and refine our ideas'.

Bundling: Prioritizing circular opportunities. The bundling process helps SMEs identify, evaluate and refine CE opportunities using structured methods. It prioritizes initiatives based on their potential environmental and economic benefits. The first step, assessing CE initiatives with lifecycle metrics, relies on frameworks that measure impacts throughout the product or process lifecycle. Key metrics include material recovery, carbon reduction and cost savings, guiding sustainable decisions. For example, the CEO from SME B commented:

'We used lifecycle metrics to compare two ideas, modular design and a repair programme. Turns out, modular design was the clear winner when it came to cost savings and scaling up'.

The second focus, testing circular initiatives through pilot loops, is an experimental approach to assess CE initiatives on a small scale. Pilot loops generate insights into technical, operational and market challenges, helping identify barriers and opportunities before full implementation. This minimizes risks and enables iterative learning, supporting the refinement and scaling of circular practices within organizations. For instance, the manager from SME D explained: 'We ran a pilot loop for modular product assembly on one of our production lines. It wasn't perfect, but it taught us a lot about the cost savings and how customers felt about the new approach'. Finally, refining circular strategies via pilot data is an iterative feedback loop in CE initiatives, where analysing pilot results identifies inefficiencies, barriers and areas for optimization. Rooted in adaptive learning and continuous improvement, this process systematically enhances technical, operational and market aspects of circular initiatives.

During cognitive realignment, manufacturing SMEs shift from reactive to proactive CE strategies, building capabilities for systemic alignment and sustainable growth.

Within the structural reconfiguration stage. The reconfiguration stage is a key phase where SMEs implement CE principles by restructuring systems, fostering stakeholder collaboration and optimizing resources to enhance circular value. It involves three core processes: embedding, orchestrating and optimizing.

Embedding: Institutionalizing circular competencies. The embedding process systematically integrates CE principles into SMEs' organizational structures and decision-making, facilitating the institutionalization of circular capabilities. It involves redesigning frameworks to include CE-specific roles, workflows and governance, creating capacity for systemic change and sustaining circular practices. This reconfiguration aligns operations with resource efficiency, waste minimization and closed-loop systems, while fostering internal accountability and cross-functional collaboration to embed circular objectives into core processes. For example, SMEs may create dedicated roles, such as 'Circular Economy Coordinator', tasked with leading initiatives like resource recovery and closed-loop product systems.

The second focus, designing multidimensional circularity metrics, involves creating evaluative frameworks to assess circularity across multiple areas like material flows, lifecycle impacts and resource retention. These metrics are key tools for measuring CE effectiveness, helping SMEs evaluate performance, spot inefficiencies and inform decisions. For instance, the manager from SME D shared: 'Figuring out how to measure circularity was tough at first, but once we started using material flow analysis, it was like a lightbulb moment. Then, we could actually see where we were losing value and where we had room to improve'.

Finally, integrating priorities into decision architectures involves embedding CE principles into organizational decision-making frameworks like procurement, investment and innovation strategies. This aligns decision structures with circular goals, ensuring resource efficiency, lifecycle and sustainability are consistently considered in strategic and operational choices. For example, the CEO from SME D indicated: 'Changing our procurement policies to include circularity made a huge difference. Now, every decision we make … like choosing suppliers … goes through filters for recyclability and carbon impact, which helps us stay aligned with our sustainability goals'.

Orchestrating: Coordinating stakeholder synergies. The orchestrating process involves coordinating with external stakeholders to develop and implement circular solutions, using shared value frameworks, resource-sharing platforms and collaborative governance. The focus on designing collaborative circular business models involves creating innovative frameworks like product-as-a-service or shared ownership that emphasize co-creation and mutual value, enabling resource efficiency, extending product lifecycles and promoting systemic circularity while addressing stakeholder interdependencies. For example, the CEO from SME A indicated: 'Introducing a rental model for our products marked a significant milestone. It not only introduced a new revenue stream but also inspired our suppliers and customers to approach circularity from a fresh perspective'.

The second focus, facilitating resource-sharing platforms, is envisioned as developing systems that allow stakeholders to exchange resources, data and expertise to promote CE innovation. These platforms are seen as vital enablers of collaborative efficiency, fostering synergies across value chains, reducing resource redundancies and speeding up the co-creation of circular solutions. By providing coordinated access to shared assets, such platforms improve the scalability and systemic impact of CE initiatives. For example, the CEO of SME C illustrated: 'We set up a digital platform where suppliers can share their ideas and innovations around recyclable materials. It's been amazing for bringing people together and solving problems as a team'.

The final focus on circular governance involves developing transparent, ethical and accountable structures for multi-stakeholder collaborations. It emphasizes implementing clear policies, oversight and decision-making to effectively manage partnerships. These structures are vital for aligning stakeholder interests, reducing conflicts and building trust, facilitating coordinated CE initiatives. For instance, the CEO from SME

E said: 'Bringing in supplier codes of conduct has really helped us keep our partners accountable when it comes to circular practices. It's also built a sense of trust and openness that makes working together so much easier'.

Optimizing: Maximizing circular value flows. The optimizing process enhances resource flows and lifecycle value using iterative design, lean practices and lifecycle initiatives. Focused on continuous improvement, iterative redesign aims to boost product modularity, durability and efficiency, applying design thinking to refine circular outcomes. By addressing design limitations and adopting circularity principles, firms can improve resource use, extend product lifespans and enable closed-loop systems. For example, the manager from SME C shared: 'Prototyping modular components has fundamentally changed the way we approach our products. Repairs have become more straightforward, recycling is more efficient, and most importantly, our customers are saving money on upgrades, which has fostered a strong sense of loyalty'.

The second focus, streamlining resource flows, targets removing inefficiencies in material and energy systems. It is a key mechanism for aligning operations with CE goals, reducing waste and optimizing resource use. This improves production efficiency, preserves material value, enhances lifecycle performance and reduces environmental impacts. For instance, the manager from SME D supported that: 'Switching to lean practices in our production was a turning point. We didn't just cut material waste. You know, we completely reimagined how we operate. It's driving real change, helping us work smarter while pushing us closer to our sustainability goals. This isn't just progress. I would say it's momentum'. Finally, lifecycle value engineering optimizes product and process value across their lifecycle by emphasizing repairability, recyclability and resource recovery. This enhances resource efficiency, supports circular flows and extends product lifespan in CE systems. For example, the manager from SME described that: 'The idea of designing for disassembly unlocked opportunities we never expected. Valuable components are no longer thrown away; instead, they are recovered, high-value parts are resold, and a new revenue stream has emerged. This shift has completely changed the way we work'.

During structural reconfiguration, SMEs build the mechanisms to implement CE principles. By integrating CE goals into structures, fostering external collaborations and optimizing resources, they align operations with circularity. These processes institutionalize circular skills, improve synergies and enhance lifecycle value.

Within the institutionalized evolution stage. The institutionalized evolution stage involves integrating CE principles into SME governance and operations, supporting ecosystem transformation. This stage is characterized by two processes: leveraging and engaging.

Leveraging: Institutionalizing circular systems. The leveraging process aims to enhance CE capabilities in SMEs by integrating circular principles into governance, standardizing operations and developing adaptable systems. Formalizing circular governance involves embedding CE principles into leadership, decision-making and strategy, aligning with governance theories that emphasize embedding sustainability for long-term value. For example, the CEO from SME A shared: 'Having a good team to lead our circular practices gave us the structure we needed to align our circular capability development with sustainability'.

The second focus on standardizing circular operations emphasizes applying CE practices like modularity, repairability and resource recovery across production systems. This aligns with operational standardization theories that stress establishing uniform procedures to boost efficiency, scalability and sustainability adoption. For instance, the manager from SME C explained: 'To standardize modularity in our designs has made it so much easier to repair and recycle our products. You know, I would make it like it's now second nature in everything we do'. Finally, enhancing system adaptability involves creating mechanisms enabling SMEs to adjust CE processes to regulatory changes and market demands. This aligns with the dynamic capabilities perspective, stressing organizational adaptability in responding to environmental shifts and seizing new opportunities. For example, the manager from SME D noted: 'Such a process opened up entirely new opportunities for sustainability and innovation'.

Engaging: Transforming ecosystem dynamics. The process promotes inter-industry collaboration to drive systemic change by aligning standards, forming partnerships and fostering synergies. It focuses on promoting sector-wide CE standards like modularity and repairability to align stakeholders around shared sustainability goals. This creates a cohesive framework for adopting circular practices, supporting ecosystem transformation based on shared norms change. For instance, SMEs may collaborate with regulatory bodies to develop universal CE standards. The CEO from SME B shared: 'We had worked with regulators closely, which helped shape modularity standards. This has ensured that the entire ecosystem moves forward together, making circularity more achievable for everyone'. The second focus, establishing closed-loop partnerships, emphasizes building collaborative relationships to close material loops and recover resources. Based on shared value theory, this approach aligns the goals of SMEs with suppliers, recyclers and logistics providers to create economic and environmental benefits. Partnerships with recyclers and logistics can support efficient recovery and reuse of products, promoting resource circularity. Encouraging inter-industry symbiosis involves creating networks for exchanging by-products, waste or surplus resources, supporting circular ecosystems. This matches network theory, highlighting the importance of interconnected systems in fostering innovation, resource efficiency and systemic change in industrial networks. The CEO from SME C remarked that: 'Our partnerships with other firms, and stakeholders from the ecosystem, or the industry, have turned what used to be waste into valuable resources, creating benefits for everyone involved'.

These processes position SMEs as leaders in sustainability, enabling them to advance their CE capabilities while driving ecosystem-level transformation.

Achieving net-zero obligation

SMEs develop CE capabilities through three stages to meet net-zero goals. The first stage, optimizing resource use, focuses on efficiency and waste reduction by integrating circular practices like recycling, reuse and repair. Based on resource efficiency and eco-design, it aims to minimize resource inputs and maximize recovery. Key activities involve designing repairable and recyclable products, creating closed-loop systems and improving processes to cut resource use. These practices support sustainable management by reducing environmental impact while maintaining economic viability. As the CEO of SME A shared, 'We started by taking a hard look at our processes and asking, 'Where are we wasting the most?' It wasn't just about saving money. I think it was about making better use of what we already had'. These actions create the groundwork for deeper decarbonization efforts in subsequent stages, reducing environmental impact while strengthening the CE capability.

Building on initial efficiencies, the next phase shifts to low-carbon energy systems by decarbonizing infrastructure through renewables, aligning with energy transition theory and sustainable goals. It replaces fossil fuels with renewable, low-carbon options, significantly reducing emissions. SMEs restructure energy systems to meet sustainability goals and lower their carbon footprint under climate action frameworks. The CEO from SME C explained, 'We started small with solar panels and energy-efficient equipment, and as soon as we saw the savings and impact, we scaled it up. It's been a win-win for us'. SMEs achieve immediate and substantial emissions reduction through prioritizing renewable energy adoption and energy-efficient technologies. This phase not only aligns their operations with global climate goals but also reinforces their commitment to long-term CE capability development.

Building on optimizing processes and transitioning to low-carbon energy, the next phase focuses on decarbonizing the entire value chain by targeting emissions in upstream and downstream activities. It aligns with frameworks that emphasize systemic collaboration to mitigate emissions. SMEs partner with suppliers, logistics providers and customers to adopt strategies like sustainable sourcing, energy-efficient transportation and circular design. These efforts exemplify supply chain management theories, emphasizing inter-organizational coordination for sustainability. As the manager from SME D explained, 'To be honest, this was the hardest part…to get suppliers and partners on the same page. But once we started working together, we found so many opportunities to cut emissions and costs at the same time'.

Achieving climate alignment targets residual emissions impossible to eliminate through operational improvements or decarbonization. Based on climate neutrality frameworks, SMEs use reforestation, carbon capture and offsets to balance emissions, aligning with environmental management theories promoting compensatory measures for net-zero goals. The manager from SME B shared, 'We understand that we can't eliminate every emission immediately, so using offsets and carbon removal is essential for us to reach Net Zero. It's not a perfect solution, but it's a practical step we need to take right now'.

Through the three stages of CE capability development, SMEs strengthen their circular practices and progress towards achieving net-zero.

Discussion

Theoretical implication

This study significantly advances the literature by focusing on the developmental and evolutionary processes of CE capability, especially within SMEs aiming for net-zero targets. It introduces a detailed process model that captures the dynamic, iterative and firm-specific nature of CE capability evolution. While previous research emphasizes CE capability's importance for sustainable performance (e.g. Bag *et al.*, 2021; Centobelli *et al.*, 2021; Zeng *et al.*, 2017), it often overlooks how these capabilities emerge and mature, implicitly assuming they are fixed traits. Challenging this view, the study argues CE capability is an emergent outcome of continuous development. The process model explicitly explains the mechanisms and dynamics behind CE capability growth, offering a nuanced understanding of how firms develop and adapt these capabilities over time. This contribution enriches the CE literature and lays a foundation for future research on capability development towards sustainability.

Second, his study advances the literature by linking CE capabilities with dynamic capabilities. While prior work acknowledges their relevance (e.g. Awan, Sroufe and Shahbaz, 2021; Köhler, Sönnichsen and Beske-Jansen, 2022; Sahoo, Upadhyay and Kumar, 2023), it often lacks clear explanations of operationalization within CE. This research addresses this gap through process models mapping dynamic capability stages to CE activities, including sensing opportunities, seizing solutions and transforming systems, aligned with DCT's core dimensions. This integration offers insights into how firms develop and implement CE capabilities through dynamic, iterative processes, strengthening the connection between DCT and CE.

Finally, this study advances the literature by focusing on CE capabilities in manufacturing SMEs, offering industry-specific insights into addressing sustainability challenges. While SMEs are recognized for their role in sustainability (e.g. Álvarez Jaramillo, Zartha Sossa and Orozco Mendoza, 2019; Journeault, Perron and Vallières, 2021; Sharma *et al.*, 2021), they are often viewed as a homogeneous group. This oversimplifies sector-specific complexities, especially in manufacturing, a resource-intensive, environmentally impactful sector with strict regulations. By concentrating on manufacturing SMEs, the study highlights unique challenges and opportunities in developing CE capabilities. This sector's characteristics, such as reliance on material inputs, supply chain intricacies and operational rigidity, shape how CE capabilities evolve, deepening understanding of how manufacturing SMEs navigate constraints, seize opportunities and meet net-zero goals.

Practical implication

The findings offer several practical implications. First, during the cognitive realignment stage (sensing circular opportunities), managers might focus on raising awareness of sustainability within their organizations and exploring ways to integrate circular principles into operations. Managers might stay informed about market trends, regulatory changes and industry developments to identify circular opportunities. Organizing team workshops or brainstorming sessions might also encourage employees to share innovative ideas and contribute to the organization's circular vision. Second, in the structural reconfiguration stage (seizing circular solutions), managers might prioritize implementing practical changes, such as redesigning products for sustainability, adopting circular production processes or exploring business models like reuse or product-as-a-service. Managers might start with small pilot projects to test ideas before scaling them. Collaborating with technology providers, academic institutions or industry consortia might provide access to resources, expertise and tools that can support these efforts. Finally, during the institutional evolution stage (transforming circular systems), managers might focus on embedding circularity into the organization's culture and long-term strategies. This could involve setting measurable sustainability goals, tracking progress and collaborating with external stakeholders, such as suppliers and customers, to align efforts and create shared value. Managers might also foster trust and open communication in partnerships to strengthen collaboration and ensure long-term success in meeting CE goals.

Limitations

This study presents several limitations that may affect its scope and generalizability. First, the use of snowball sampling and personal networks to select six SMEs introduces potential selection bias, likely favouring firms already engaged in CE practices and limiting diversity of perspectives. Second, the focus on manufacturing SMEs in Zhongguancun, Beijing, further narrows applicability to other sectors or regions with different regulatory and market conditions. Third, while the qualitative multiple case study approach offers rich insights into CE capability development, it restricts broader generalization. These factors call for caution in interpreting the findings and underscore the need for validation across varied contexts.

Future research directions

The proposed three-stage model (Figure 5), integrated with DCT's sensing, seizing and transforming processes, invites several avenues for empirical validation and extension. Quantitative studies could test its predictive strength by surveying manufacturing SMEs using variables such as sensing capacity (e.g. environmental scanning), seizing actions (e.g. investment in circular technologies) and transformation outcomes (e.g. closed-loop system adoption), regressed against CE performance metrics like material recovery or carbon reduction. Longitudinal research over 3–5 years would capture the iterative nature of DCT, revealing how external forces like policy shifts or market changes influence progression through the model. Comparative studies across firm sizes or sectors could assess generalizability, examining how resource availability and flexibility shape CE capability development. Multi-tier supply chain analyses may uncover how upstream and downstream actors influence SMEs' institutional evolution, especially in value chain reconfiguration. Integrating complementary theories such as the resource-based view could further explore how tangible assets moderate CE transitions. Finally, action research or intervention studies could produce practical tools like DCT-based workshops or metrics for structural reconfiguration, to support SMEs in achieving net-zero goals. These studies could extend the model to diverse global contexts, such as emerging economies or regions with varying CE policy frameworks, enhancing its applicability and impact.

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