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RESEARCH ARTICLE

Catalysing the Circular Economy in SMEs: A Systematic Review of Digital Tools, Barriers, and Enablers

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Abstract

This paper presents a systematic literature review, conducted following the PRISMA 2020 framework, to investigate the role of digital and technological tools in facilitating Circular Economy (CE) adoption within small and medium-sized enterprises (SMEs). Despite their critical contribution to global economies, SMEs encounter significant barriers, including financial constraints, technological complexity, and regulatory ambiguities that hinder their transition to circular models. This review synthesises evidence from 45 peer-reviewed journal articles, case studies, and industry reports published between 2018 and 2025. The findings demonstrate how technologies such as AI, IoT, and blockchain enhance resource efficiency, supply chain transparency, and product lifecycle management. Key enablers identified include government subsidies, targeted training programmes, and collaborative innovation networks, which collectively mitigate adoption barriers. Employing a critical analytical lens, this review moves beyond cataloguing tools, synthesising findings into an integrative framework that links SME digital maturity with circular innovation capacity. The study offers a unique theoretical contribution by merging the discourse on digital transformation with circular economy principles within the specific context of SMEs, an area that has not been thoroughly examined. Practically, it offers actionable implications for SME managers, policymakers, and technology developers, advocating for tailored, cost-effective digital solutions and coherent policy frameworks. By mapping the current research landscape and proposing a focused agenda for future inquiry, this review aims to accelerate sustainable innovation and bolster the competitiveness of SMEs in an evolving circular economy.

Keywords Blockchain · Circular Economy (CE) · Digital Tools · Small and Medium Enterprises (SMEs) · Sustainability

1. Introduction

The Circular Economy (CE) model presents a transformative paradigm to address the pressing global challenges of resource depletion, environmental degradation, and waste generation. Diverging from the conventional linear take-make-dispose model, the CE emphasises closed-loop systems designed to retain the value of products, materials, and resources for as long as possible (Huynh, 2024). Small and Medium-sized

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Enterprises (SMEs) are central to enabling this shift towards a more sustainable economic model, constituting approximately 90% of businesses globally (Circular4.0 Project, 2024).

This situation presents a critical paradox: while digital tools are heralded as key enablers for CE, the very entities that constitute most of the global economy, SMEs, are often least equipped to adopt them due to a lack of financial resources, technical competencies, and access to enabling technologies (Das, 2025; Chakraborty et al., 2024). Consequently, this review aims not merely to catalogue tools and barriers but to critically analyse the interplay between SME-specific constraints and digital-CE solutions, offering a pathway to bridge this adoption gap.

In recent years, the adoption of CE is increasingly facilitated by solutions that are digital and technological in nature. Despite such potential, their applications remain under-explored within the SMEs because these firms lack the scale and specialised expertise in technology that characterises larger corporations. SMEs encounter distinct obstacles, including substantial initial expenses, limited digital literacy, and insufficient institutional support, all of which hinder the adoption of CE-enabling technologies (Council for Inclusive Capitalism, 2024; Khan et al., 2022). Therefore, understanding how to eliminate these obstacles and leverage key enablers is important in facilitating the widespread adoption of CE practices within SMEs (Chakraborty et al., 2024; Dutra et al., 2024).

While SMEs are central to the circular economy transition, the interface of digital tools such as AI, IoT, and blockchain and their operationalisation in SME contexts remains nascent area of research. Given that much of the literature on Industry 4.0 applications tends to focus on large firms, there is a very evident lacuna regarding systematic reviews that synthesise how SMEs can use digital tools in specific CE domains such as reverse logistics, product life extension, and waste-to-resource loops. This gap justifies the present systematic review.

This study has several implications. First, it will prove highly germane in the quest to resolve the gap that is considered critical between CE and the digital transformation of SMEs. The finding will offer SMEs and business executives practical insights to overcome barriers to adoption and leverage opportunities. Policymakers and technology providers can utilise the results to formulate enabling policies, targeted funding, and tailored technological solutions that support SMEs in transitioning towards a global circular economy. By focusing on SMEs, an indispensable yet frequently overlooked segment of the economy, this study addresses the urgent imperative for sustainable resource utilisation and enhanced environmental stewardship.

The objectives of this research are fourfold:

1. To map how digital and technological tools (e.g., AI, IoT, blockchain) are currently applied to CE adoption in SMEs.
2. To identify the specific SME contexts and circular economy domains (design, production, recovery, reuse) where digital tools are underutilised.
3. To synthesise key barriers and enablers associated with digital tool adoption for CE in SMEs.
4. To propose future research directions that bridge the digital-CE gap in SME settings.

The review is guided by three principal research questions: (1) What are the most significant technological and digital resources required for SMEs to adopt CE? (2) What are the major challenges for SMEs in leveraging these resources? (3) What enabling factors can empower SMEs to employ technology for CE practices? By synthesising insights from extant academic literature and industry reports, this review aims to provide a concise overview of the current research landscape and pinpoint critical avenues for future inquiry.

The rest of this paper will be structured as follows: Section 2 theoretical framework and literature review. Section 3 methodology. Section 4 discusses the results. Section 5 covers thematic implications, enablers/barriers to implementation, and future studies. Section 6 conclusion.

2. Theoretical Framework and Literature Review

2.1. The Circular Economy: Definition and Key Principles

The Circular Economy (CE) constitutes a systemic shift away from the traditional linear economic model of take-make-dispose towards a regenerative and restorative framework. This paradigm prioritises resource

efficiency, waste minimisation, and long-term sustainability. Its core principles, as articulated by the Ellen MacArthur Foundation (2023), involve designing out waste and pollution, keeping products and materials in use, and regenerating natural systems. In practice, CE facilitates value retention through strategies such as reuse, repair, remanufacturing, and recycling, thereby fostering sustainable consumption and production patterns (Singh et al., 2025).

Contemporary scholarship accentuates the strategic role of CE in building environmental resilience, particularly in developing economies where challenges of waste mismanagement and resource inefficiency are often more acute (Kumba et al., 2024). Within the Small and Medium-sized Enterprise (SME) context, CE is rapidly emerging not merely as an environmental imperative but also as a significant business opportunity to enhance operational efficiency, access new markets, and comply with evolving sustainability legislation (Muzamwese et al., 2024). The development of green capabilities is increasingly recognised as a critical driver for achieving superior environmental and economic performance, positioning CE as a core strategic objective rather than a peripheral concern (Khan et al., 2022).

SMEs face unique challenges in adopting CE practices: they often lack sufficient digital infrastructure, have lower technology absorption capacity, limited managerial IT skills, and constrained access to external networks. For instance, Gianaroli et al. (2024) found that SMEs implementing AI-enabled circular manufacturing systems faced barriers in data collection and analytics capabilities. These challenges are further contextualised by sector-specific studies; for example, research on horticulture SMEs in Zimbabwe highlights how barriers like limited access to green financing and technical skills are acutely felt in agro-based economies, while enablers like strong local community networks can be leveraged (Muzondo, Mashapure, & Masiiwa, 2025).

While digital tools such as IoT sensors for material flow monitoring, machine-learning algorithms for predictive reuse, and blockchain for circular supply chains are recognised as key enablers, empirical evidence of their application within SME settings remains fragmented and limited (Natrajan et al., 2024; Alab et al., 2025). Consequently, this review seeks to narrow its focus on the specific CE domains, such as design, production, recovery, and logistics, where digital tools are being applied in SMEs, and to identify where critical gaps in application and research persist.

2.2. Digital Tools and the Enhancement of CE Adoption in SMEs

Digital technologies play a role in enabling SMEs to adopt circular economy concepts by leveraging data-related approaches for enhancing material traceability, energy efficiency, and lifecycle performance. IoT, AI, and blockchain technologies have been identified among those that play a significant role in implementing circular economy concepts by offering required levels of transparency, traceability, and flexibility.

Recent research has shown that SMEs that have integrated digital platforms are in a better position to identify areas of operational inefficiency and reduce supply chain waste significantly (Muzondo, Matowanyika, & Chipangamate, 2025). For example, AI-driven analytics for predictive maintenance can provide insights for SMEs to anticipate equipment needs in advance so that material waste is reduced and equipment lifespan prolonged. In the same vein, continuous improvement and conformance with the principles of the circular economy are possible through the use of IoT sensor-based monitoring as a means of instant feedback about resource flow.

Despite this transformative potential, the majority of SMEs make inadequate use of digital technologies owing to continuous binding constraints in the form of financial limitations, unavailability of adequate digital competencies, and strategic guidance (Khan & Mihaisi, 2023). In relation to this, Arranz et al. (2024) also noted that feasibility and resource limitations are peculiar for SMEs, making integration strategies incremental and particularly essential to the adoption of the CE models.

The emergence of Industry 5.0 offers pathways to these barriers. Collaborative innovative hubs, digital platforms, and policy-driven ecosystems have become catalysts by combining human-centric AI, robotics, digital twins, and smart automation to fast-track the adoption of CE in SMEs (Santos, 2024; Alab et al., 2025). For instance, resource-loop simulations can be made possible through digital twin models, predictive maintenance helps in life-extending assets, and blockchain supports better traceability of secondary materials. Natrajan et al. (2024) argued that recent systematic reviews confirm the transformative potential of digital twins for supply chain visibility and resilience but also reveal a significant gap regarding their application

within SME-specific contexts. These digital enablers remain underrepresented in SME-CE research, and thus focused investigation is urgently needed.

2.3. Definition of Key Digital Technologies

This review focuses on the following technologies:

- **Artificial Intelligence (AI) and Machine Learning:** Systems that analyse data to predict outcomes, optimise processes (e.g., predictive maintenance, demand forecasting), and automate decision-making in CE loops.
- **Internet of Things (IoT):** Networks of physical sensors that collect real-time data on resource flows, equipment status, and product location, enabling monitoring and efficiency gains.
- **Blockchain:** A decentralised digital ledger providing immutable, transparent records of transactions, used for enhancing traceability and trust in circular supply chains (e.g., material provenance).
- **Digital Twin:** A virtual, dynamic replica of a physical asset or system, used to simulate, analyse, and optimise performance for life extension and waste reduction.
- **Augmented Reality (AR):** Technology that superimposes digital information onto the physical world, aiding in repair, remanufacturing, and training.

3. Methodology

This systematic literature review was conducted following the PRISMA 2020 statement by Page et al. (2021), which aims to ensure a transparent, reproducible, and methodologically rigorous process. A predefined review protocol was developed in accordance with PRISMA-P guidelines and is available upon request. The primary aim of this study was to systematically screen, identify, and analyse peer-reviewed studies from 2018 to 2025 that investigate the use of digital and technological tools for the adoption of the CE among SMEs. The date range (2018-2025) was selected to capture literature from the advent of widespread Industry 4.0 discourse and the contemporary, rapidly evolving digital-CE nexus.

Clear inclusion and exclusion criteria were developed to define the scope of the review. The inclusion criteria comprised

a) studies explicitly focusing on SMEs, usually defined as firms with less than 250 employees;
b) research that explicitly addresses the adoption of CE or the implementation of a circular business model; and
c) Studies related to the use of particular digital or technological tools (like AI, IoT, blockchain, or digital twins) in the context of SME–CE.

The exclusion criteria excluded:

a) studies concentrated only on large enterprises;
b) publications in languages other than English;
c) conference abstracts or briefs without available full-text articles.

A comprehensive search strategy was performed in three major academic databases: Scopus, Web of Science, and Google Scholar. It had the following keyword combinations: SME and circular economy and digital technology; SME and circular economy and AI; and small and medium enterprise and circular economy and blockchain. The complete search strings used for each database are detailed in Table 1. The database search provided 210 records.

Table 1. Systematic Review Search Strategy (*Source: Authors (2025)*)

Database	Search String
Scopus	TITLE-ABS-KEY, small and medium enterprise OR SME OR SMEs AND circular economy OR circular AND digital OR technology OR artificial intelligence OR AI OR internet of things OR IoT OR blockchain OR digital twin AND PUBYEAR > 2017
Web of Science	TS= small and medium enterprise OR SME OR SMEs AND circular economy OR circular AND digital OR technology OR artificial intelligence OR AI OR internet of things OR IoT OR blockchain OR digital twin AND PY= (2018-2025)
Google Scholar	small and medium enterprise circular economy digital technology (the first 200 relevant results were screened)

After removing duplicates and performing an initial screening of titles and abstracts against the inclusion criteria, 60 studies remained to undergo a full-text eligibility assessment. Finally, after a rigorous full-text review, 45 studies that met the criteria were included for final analysis and data extraction.

All included studies underwent a quality appraisal using the Critical Appraisal Skills Programme (CASP) checklist for qualitative and case study research. Findings from studies with lower methodological ratings were treated with greater caution and did not form the primary basis for the review's conclusions.

In order to reduce selection bias and improve reliability, the full-text studies were screened and coded by three independent researchers using NVivo software. The analysis followed an inductive thematic approach. An initial codebook was developed by two authors, piloted on a subset of five studies, and refined. Inter-coder reliability was assessed using Cohen's Kappa ($\kappa = 0.82$), indicating substantial agreement. Discrepancies in coding and eligibility assessment were solved through consensus meetings. Presenting the review process in accordance with the PRISMA 2020 flow diagram (Page et al., 2021), thematic analysis was used to identify, analyse, and report on patterns (themes) across the dataset (Braun & Clarke, 2022). This helped to synthesise the key barriers, enablers, and linkages between digital tools and specific CE domains.

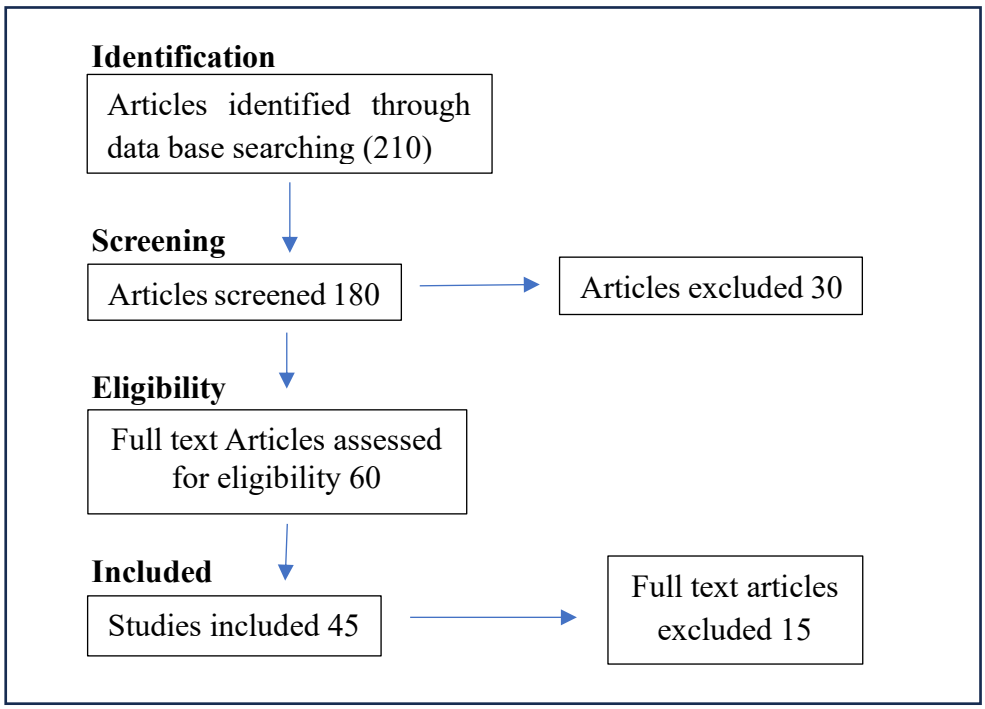

Figure 1. PRISMA 2020 Flow Diagram of the Article Selection Process (Page et al., 2021)

4. Results

4.1. Overview of Selected Studies

This systematic review includes 45 studies published between the years 2018 and 2025 to provide a state-of-the-art review of digital tools in circular economy adoption for SMEs. A total of 30 journal articles, 10 case studies, and 5 industry reports were included in the final collection because they had direct relevance to the study. The distribution of these publications is summarised in Table 1. It is noteworthy that the predominance of journal articles (67% of the sample) may reflect a higher volume of conceptual or survey-based research, while the relatively smaller proportion of case studies (22%) and industry reports (11%) suggests a potential gap in rich, practice-based empirical evidence documenting real-world SME implementation challenges and outcomes.

Table 2. Summary of the Types of Studies Included (*Source: Authors (2025)*)

Type of Study	Number of Studies
Journal Articles	30
Case Studies	10
Industry Reports	5
Total	**45**

4.2. Key Findings

This synthesis shows that digital technologies are significant enablers of CE practices in SMEs. Key enablers include AI, IoT, blockchain, data analytics, cloud computing, and AR. AI systems are used to provide predictive analytics, which can enhance waste management and resource utilisation, with the effect of improving sustainability outcomes (Klimecka-Tatar & Kapustka, 2025; All Noman et al., 2022). IoT technologies allow SMEs to monitor in real time and thus improve operational efficiency. Such systems could reduce energy-related costs and emissions of SMEs by 20% (Teixeira et al., 2022). However, these efficiency gains are context-dependent; for instance, studies from regions with unstable digital infrastructure (e.g., Khan & Mihaisi, 2023) report that IoT reliability and associated savings can be significantly lower, highlighting a disparity not fully captured in aggregated findings. Blockchain builds transparency and traceability into the supply chains, preconditions for which there is no substitute to reach effective circularity. According to Peerally et al. (2025), blockchain can enable clarity and traceability within supply chains, acting as a foundation for effective circularity. Data analytics tools identify areas of inefficiency throughout production, yielding as much as 25% in waste reductions (Teixeira et al., 2022). Cloud computing enables resource sharing and the development of circular ecosystems among supply chain networks (Urbinati et al., 2022). Lastly, AR supports worker activities for product repair and remanufacturing, thereby extending the lives of products and reducing waste. This is demonstrated in the discussion by Urbinati et al. (2022), where a specific case reported product longevity had increased by 15% due to AR-based interventions. Empirical evidence also highlights the development of the emerging role of AR and digital twins. For instance, AR-based training in Zimbabwean textile SMEs reduced remanufacturing errors by up to 22% (Mashoko, 2025). Similarly, with digital twins in Portuguese furniture SMEs, real-time resource simulation was possible, thereby improving material efficiency by 17% (Soriano-Pinar, Díaz-Garrido, & Bermejo-Olivas, 2023).

4.3. Applications of Digital Tools in CE Practices

These 45 studies have been classified by technology type, by CE domain, and by geography in order to map the patterns of application. From Table 2, the most researched areas are AI in production with 22% (n=10) and blockchain for reverse logistics with 18% (n=8), whereas digital twin applications are particularly scant, appearing in only 5% (n=2) of the studies. This skewed distribution suggests a research focus on established, higher-maturity technologies (AI, blockchain) in specific operational domains (production, logistics), while

emerging tools like digital twins, crucial for simulating complex reuse loops, remain critically underexplored in the SME context.

Table 3. Summary of Included Studies by Digital Technology, Circular Economy (CE) Domain, and Geographical Region (n = 45) (*Source: Authors (2025)*)

Digital Technology	CE Domain	Region	Count (n)	% of Sample
AI	Production	Europe	10	22%
AI	Design	Asia	5	11%
Blockchain	Reverse Logistics	Asia	8	18%
Blockchain	Recovery	North America	4	9%
IoT	Logistics	Europe	6	13%
IoT	Reuse	Africa	3	7%
Digital Twin	Reuse	Europe	2	5%
Other Technologies*	Various CE domains	Global	7	15%

*Other technologies include big data analytics, cloud computing, augmented reality, etc.

These digital technologies are increasingly applied across critical CE practices. AI and big data analytics facilitate Life Cycle Assessment (LCA); for example, textile SMEs implementing LCA achieved a 32% offset of generated waste through material reuse (Raman et al., 2025). Blockchain streamlines reverse logistics, enabling product recovery rates of up to 40% (Mathebula, 2022). IoT sensors optimise material flows; for instance, an IoT-enabled inventory system led to a 21% reduction in generated waste by one agricultural SME (Pereira et al., 2022). López Pérez et al. (2023) believe that cloud computing technology promotes collaborative supply chains, leading to a 15% increase in materials utilisation in the food sector. A notable contradiction arises in the literature regarding blockchain: while multiple studies tout its potential for supply chain transparency (e.g., Peerally et al., 2025), several case studies (e.g., in agro-based SMEs) point to its implementation complexity and high operational costs as prohibitive factors, suggesting its role may be more aspirational than practical for many SMEs at present.

4.4. Barriers and Enablers

The comprehensive review of 45 studies revealed a complex interplay between multiple factors contributing to the adoption of digital technology CE approaches in SMEs. These factors were identified through a rigorous thematic analysis, which organised them into barriers and enablers to improve conceptual clarity. Rather than presenting these factors in isolation, Figure 2 synthesises them into an integrated framework, mapping how specific enabling mechanisms can directly address and mitigate the primary adoption barriers faced by SMEs. The recurrence of these themes in the existing literature not only reinforces current knowledge (Natrajan et al., 2024; Gianaroli et al., 2024) but also adds to it by highlighting the growing impotence of human-centric parameters in the industry 5.0 framework.

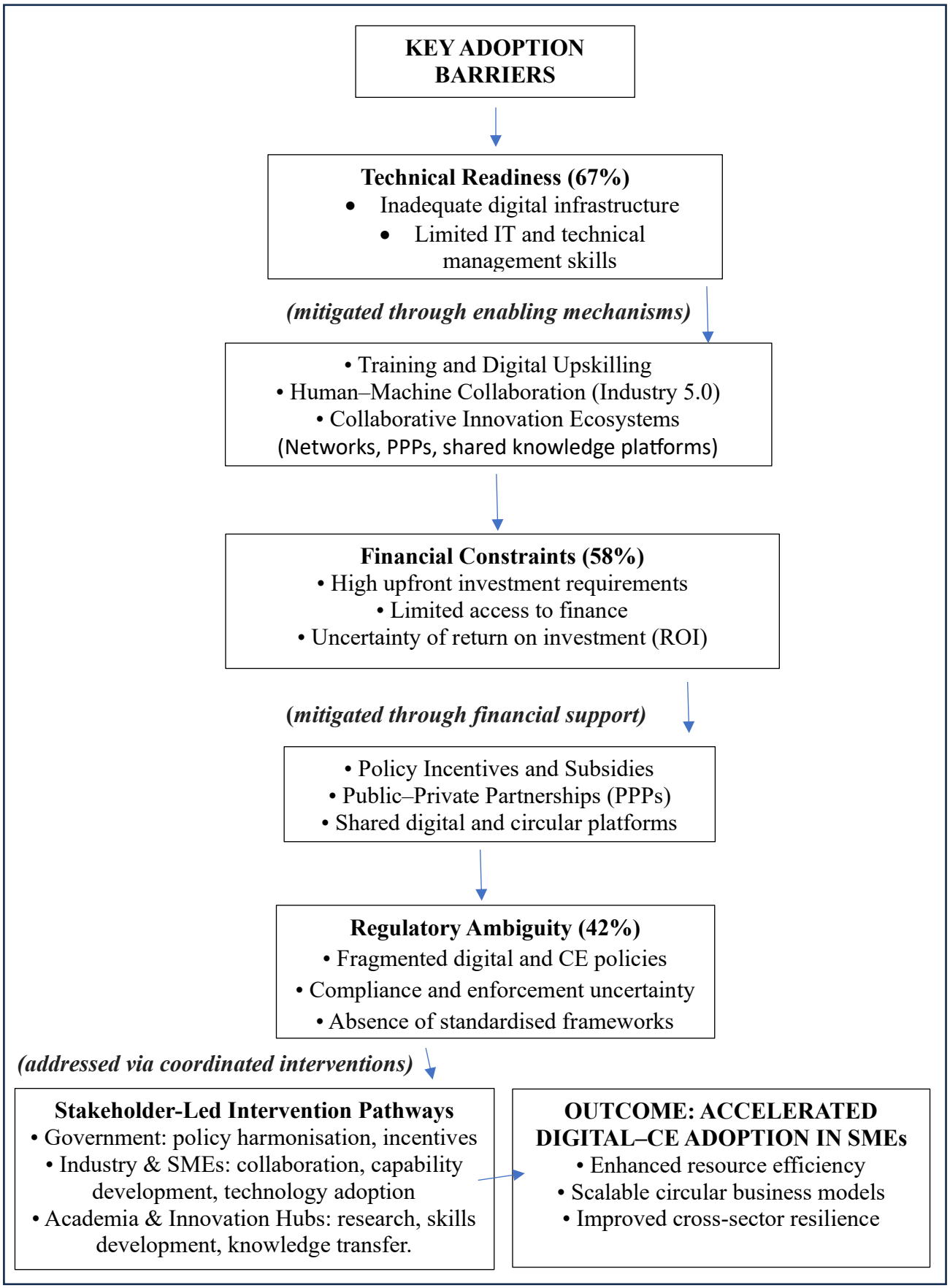

Figure 2. Integrated Framework of Barriers, Enablers, and Intervention Pathways for Digital-CE Adoption in SMEs (Source: Author 2025)

Figure 2 shows the integrated framework of barriers, enablers, and intervention pathways for digital-CE adoption in SMEs. This framework synthesises the thematic analysis, illustrating the primary barriers (technical readiness, financial constraints, regulatory ambiguity), the key enablers that address them, and the stakeholder-driven intervention pathways that facilitate the adoption process.

The analysis identified three overarching barrier categories:

1. **Technical Readiness (67% of studies):** Encompassing low digital infrastructure, limited technical skills, and inadequate IT management capabilities. This was the most frequently cited barrier.
2. **Financial Constraints (58% of studies):** Including high upfront costs, limited access to capital, and uncertainty regarding return on investment (ROI).
3. **Regulatory Ambiguity (42% of studies):** Involving unclear policy frameworks, compliance uncertainties, and a lack of standardised protocols.

Correspondingly, four primary enabler categories were identified, which directly counteract these barriers:

1. **Training and Digital Upskilling:** Addresses the Technical Readiness barrier by building internal competencies.
2. **Policy Incentives and Subsidies:** Mitigates Financial Constraints through targeted financial support, tax credits, and grants.
3. **Collaborative Ecosystems (e.g., Innovation Networks, PPPs):** Helps overcome both **Technical Readiness** and **Financial Constraints** by facilitating knowledge sharing, resource pooling, and risk mitigation.
4. **Human-Machine Collaboration (Industry 5.0):** Enhances Technical Readiness by designing technology that augments, rather than replaces, existing human capabilities, making adoption more accessible.

A critical insight from the synthesis is the regional variation in barrier prominence. For instance, while financial constraints were universal, studies from developing economies (e.g., Khan & Mihaisi, 2023) emphasised digital infrastructure gaps as a more fundamental aspect of technical readiness than skills alone, a nuance less prominent in studies from developed regions.

The barrier of technical readiness was particularly prominent, appearing in 67% of the reviewed studies. In turn, technical readiness means not only a lack or insufficiency in digital infrastructure but also in competence. As noted by Omowole et al. (2024), skills deficits in digital technology go beyond just functionality; they involve digital strategic leadership skills. Invasion into data analysis skills also represents another domain that contributes to these skills deficits. These skill deficits constitute a major barrier to technology implementation.

Other major barriers are financial in nature. These include high upfront costs and a lack of access to capital. High upfront costs and lack of access to capital were again found as financial barriers in 58% of the studies. According to Neri et al. (2025), there is a major concern related to financial uncertainties for those that demand high upfront costs. Examples include IoT-based solutions and blockchain platforms, among IoT-related solutions. These financial hesitations are further compounded by the uncertainty regarding the return on investment, which makes SME decision-makers very cautious concerning technology adoption.

Ambiguity of regulation was highlighted as a challenge in 42% of the papers surveyed. Indeed, Perez-Ruiz et al. (2023) point to the concern related to compliance risk that unclear regulation presents to vendors. As has been indicated, small business owners face a dilemma in cases where they operate in jurisdictions or industry sectors with developing sustainability regulation.

In terms of enabling forces, financial incentives or subsidies have been singularly successful in overcoming the financial barriers. Ferreira (2024) document cases where targeted subsidies led to 40% increases in technology adoption rates, illustrating the powerful role of well-designed financial incentives in catalysing digital transformation.

Training and digital upskilling programmes emerge as crucial enablers for addressing technical readiness barriers. Rueda (2025) emphasise that successful implementation requires not only initial training but also continuous skill development programmes that evolve with technological advancements. This ongoing learning approach helps SMEs maintain relevance in rapidly changing digital landscapes.

Collaborative ecosystems represent another powerful enabler, facilitating knowledge sharing, skills transfer, resource pooling, and risk mitigation. Zhao and Wu (2023) describe how digital marketplaces and

innovation hubs create environments where SMEs can access advanced technologies and expertise that would otherwise be beyond their individual reach.

The emergence of human-machine collaboration as a distinct enabler marks an important evolution in understanding digital transformation in SMEs. This Industry 5.0 perspective, as noted by Santos (2024), emphasises technologies that enhance human capabilities rather than replace them, making digital tools more accessible and relevant to smaller enterprises with limited technical resources.

The dynamic interaction between these barriers and enablers suggests that successful digital-CE adoption requires coordinated efforts across multiple fronts. Financial incentives must be coupled with technical support, regulatory clarity must accompany collaborative opportunities, and technological solutions must align with human capabilities. This comprehensive approach acknowledges the interconnected nature of the challenges and opportunities facing SMEs in their circular economy journeys.

Furthermore, the regional variations in barrier prominence and enabler effectiveness highlight the need for context-specific strategies. Studies from developing economies emphasise different challenges than those from developed regions, suggesting that adoption frameworks must be adapted to local conditions, resources, and institutional contexts.

The identification of these barriers and enablers provides a foundation for developing targeted interventions and support mechanisms. By understanding the specific challenges SMEs face and the factors that can facilitate adoption, policymakers, technology providers, and SME support organisations can develop more effective strategies for accelerating circular economy transitions through digital tools.

This comprehensive mapping of barriers and enablers not only contributes to academic understanding but also provides practical guidance for stakeholders seeking to support SMEs in their digital and sustainability journeys. The findings underscore the need for holistic approaches that address multiple dimensions of the adoption challenge simultaneously, recognising that piecemeal interventions are unlikely to achieve the transformative changes required for meaningful circular economy implementation.

5. Discussion

5.1. Interpretation of Findings

5.1.1. Theoretical Contribution: Towards an SME Digital-CE Adoption Framework

This systematic review moves beyond cataloguing tools and barriers to propose an integrative framework for understanding digital-CE adoption in SMEs. As synthesised in Figure 2 (Section 4.4), adoption is not a linear process but a dynamic interplay constrained by three core barriers (technical readiness, financial constraints, regulatory ambiguity) and facilitated by four corresponding enablers (training/upskilling, policy incentives, collaborative ecosystems, human-machine collaboration). The primary theoretical contribution of this work is linking the discourse on SME digital transformation with CE transition models. Prior models (e.g., Santos, 2024; Alab et al., 2025) often treat digital maturity and circular innovation capacity as separate domains. This review synthesises them, positing that successful adoption hinges on aligning an SME's digital maturity (infrastructure, skills, data capability) with its circular innovation ambition (e.g., design for reuse, advanced recovery loops). This integrated perspective addresses the identified paradox and provides a scaffold for future empirical testing.

5.1.2. Critical Synthesis and Contrast with Existing Literature

The findings affirm digital technologies as key drivers for CE in SMEs, aligning with broader literature on digital sustainability (Gupta et al., 2025; Ferasso et al., 2023). However, a critical synthesis reveals stark contrasts with research focused on large corporations. While literature on large firms emphasises strategic digital transformation and large-scale IoT/blockchain integration, our review uncovers that for SMEs, the journey is often incremental, pragmatic, and focused on solving immediate operational inefficiencies (Arranz et al., 2024). For instance, the underutilisation of digital twins (only 5% of reviewed studies) can be directly attributed to their high demands for data integration and modelling expertise resources typically scarce in SMEs (Natrajan et al., 2024).

Similarly, while blockchain's potential for supply chain transparency is widely endorsed (Peerally et al., 2025), its complexity and cost render it aspirational rather than practical for most SMEs today, a tension noted in sector-specific cases (Mathebula, 2022).

This review also critically engages with the enabler narrative. While tools like AI for predictive maintenance are promising (Rueda, 2025), their adoption is stifled by internal organisational weaknesses often overlooked in generic models: a lack of leadership commitment, insufficient employee skills, and low innovation preparedness are as critical as external financial barriers (Muzondo et al., 2025). Therefore, our synthesis adds necessary nuance, showing that technological potential is mediated by a layer of SME-specific organisational and resource realities absent from studies of larger enterprises.

5.1.3. Practical Implications Derived from Synthesis The integrated framework (Figure 2) yields targeted implications for stakeholders:

- For SME Managers: Strategy must involve honest self-assessment using the dual lenses of digital maturity and circular ambition. Investment should prioritise building foundational digital infrastructure and data literacy before pursuing advanced technologies. Forming partnerships through collaborative ecosystems (Zhao & Wu, 2023) is a vital strategy to access technology, share risks, and acquire knowledge.
- For Policymakers: Effective support requires bundled interventions that address multiple barriers simultaneously. For example, financial subsidies (Ferreira, 2024) must be coupled with technical support and skills training programmes. Policy should incentivise human-centric technology design (Industry 5.0) that augments the existing SME workforce rather than demanding its wholesale replacement.
- For Technology Providers: To serve the SME market, solutions must be modular, affordable, and designed for usability with low technical expertise. Engaging in co-creation with SMEs and participating in innovation hubs can lead to tools that solve real, contextual problems, such as simplified digital twin platforms for reuse planning or AR-guided repair systems (Kochert, 2024).

5.1.4. Limitations and Avenues for Future Research This review has limitations that frame future research opportunities. The focus on English-language publications (2018-2025) may introduce geographic and recency bias, capturing a prominent but not fully global perspective. Furthermore, the review maps the landscape of adoption but cannot, by its nature, establish longitudinal causal links between technology use and sustainability performance.

Based on these limitations and the gaps identified in our synthesis, we propose the following focused research agenda:

1. **Contextualized Adoption Models:** Empirical studies testing integrated frameworks (like the one proposed in Section 5.1) in specific SME sectors (e.g., retail, construction) and underrepresented regions (e.g., Southeast Asia, Latin America).
2. **Scalable Digital Twins:** Research into low-cost, modular digital twin platforms feasible for SME resource constraints, focusing on specific CE loops like reuse and remanufacturing.
3. **Human-Centric Technology Design:** Investigations into how AR interfaces and collaborative robotics (Industry 5.0) can be designed for usability by low-skilled workforces in SME repair and remanufacturing settings.
4. **Ecosystem Governance:** Studies on the effective design of policy-incentive bundles and public-private innovation hubs that measurably improve digital-CE adoption rates among SMEs.
5. **Longitudinal Impact:** Multi-year case studies tracking the economic and environmental ROI of digital tool adoption in SMEs to build a stronger, evidence-based business case for investment.

6. Conclusion

This systematic literature review has underscored the indispensable yet complex role of digital and technological tools in enabling Small and Medium-sized Enterprises (SMEs) to adopt Circular Economy (CE) practices. By synthesising insights from over 45 studies, the analysis confirms the transformative potential of

technologies such as the Internet of Things (IoT), blockchain, artificial intelligence (AI), and data analytics in enhancing resource efficacy, supply chain transparency, and product life extension.

However, the central and most significant contribution of this review lies in moving beyond cataloguing tools and barriers to critically analyse the fundamental adoption paradox: SMEs are universally recognised as crucial agents for the CE transition, yet they are disproportionately hindered by financial, technical, and regulatory constraints from deploying the very digital tools that could facilitate this shift. In response to this paradox, this study makes a distinct theoretical contribution by integrating the discourses on digital transformation and CE into a novel framework for SME adoption. This framework posits that successful integration depends on strategically aligning an SME's digital maturity (its infrastructure, skills, and data capabilities) with its circular innovation ambition (the complexity of CE loops it aims to implement, from recycling to advanced reuse).

While the review systematically delineates the applications of specific digital tools across CE domains and reconfirms well-known barriers (technical readiness, financial constraints, regulatory ambiguity), its synthesis offers a higher-order pathway forward. The identified enablers—targeted training, policy incentives, collaborative ecosystems, and human-centric technology design—emerge not as a simple list, but as interconnected leverage points within the proposed framework, each acting to bridge the gap between inherent SME constraints and the requirements for circular innovation.

The implications of these findings call for concerted and coordinated action. For SME managers, the imperative is to conduct a dual assessment of digital maturity and circular ambition to guide strategic, incremental investment. For policymakers, the mandate is to create coherent, bundled support packages that simultaneously address financial, skill, and regulatory barriers. For technology providers, the opportunity lies in developing affordable, modular, and user-centric solutions tailored to the specific reality of SME operations.

In conclusion, the transition to a circular economy represents a fundamental shift towards sustainability. Digital technologies are central catalysts, but their potential in the SME sector will only be realised through strategies informed by an understanding of the specific adoption paradox and guided by integrated frameworks, such as the one advanced in this review. By embracing such a nuanced approach, SMEs can better navigate their transition, enhance their own resilience and competitiveness, and make a substantive contribution to broader environmental and economic goals.

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Declarations

Competing Interests The authors declare no competing interests.

References

Alabi, A. T., Ubandawaki, A. T., & Issa, S. O. (2025). The role of digital technology in the sustainability strategies of SMEs. In The Future of Small Business in Industry 5.0 (pp. 347-378). *IGI Global Scientific Publishing*. https://doi.org/10.4018/979-8-3693-7362-0.ch014

Alabi, A. T., Ubandawaki, A. T., & Issa, S. O. (2025). The role of digital technology in the sustainability strategies of SMEs. In The Future of Small Business in Industry 5.0 (pp. 347-378). *IGI Global Scientific Publishing*. https://doi.org/10.4018/979-8-3693-7362-0.ch014

All Noman, A., Akter, U. H., Pranto, T., & Haque, A. K. M. B. (2022). Machine learning and artificial intelligence in circular economy: A bibliometric analysis and systematic literature review. *arXiv.* https://arxiv.org/abs/2205.01042

Arranz, C. F. A., Arroyabe, M. F., & Fernandez de Arroyabe, J. C. (2024). Organisational transformation toward circular economy in SMEs: The effect of internal barriers. *Journal of Cleaner Production,* 456, 142307. https://doi.org/10.1016/j.jclepro.2024.142307

Braun, V., & Clarke, V. (2022). Thematic analysis: A practical guide. *SAGE Publications*.

Chakraborty, P., Nyiawung, M., Asiri, S., Roostika, R., Hernández, J., Telukdarie, A., Tanapaisankit, P., & Espina-Romero, C. (2024). Strategic technology adoption for sustainability performance in SMEs: A comprehensive review. *International Journal of Research and Innovation in Social Science.* https://rsisinternational.org/journals/ijriss/articles/strategic-technology-adoption-for-sustainability-performance-in-sme-a-comprehensive-review/

Circular4.0 Project. (2024). Digital technologies as enabler to foster the transition to the circular economy by the SME in the Alpine Space area. *European Committee of the Regions.* https://cor.europa.eu/en/news/stories/circular40-digital-technologies-enabler-foster-transition-circular-economy-sme-alpine-space-area

Council for Inclusive Capitalism. (2024). The circular economy toolkit: Empowering SMEs toward sustainable development. https://www.inclusivecapitalism.com/news-insights/resource/the-circular-economy-toolkit-empowering-smes-toward-sustainable-development/

Das, S. K. (2025). Investigating circularity in India's textile industry: Overcoming challenges and leveraging digitisation for growth. *arXiv preprint arXiv:2501.15636.* https://arxiv.org/abs/2501.15636

Dutra de Andrade, R., Benfica, V. C., Espinosa de Oliveira, H. V., & Suchek, N. (2024). Investigating green jobs and sustainability in SMEs: Beyond business operations. *Journal of Cleaner Production*. Advance online publication. https://doi.org/10.1016/j.jclepro.2024.144477

Ellen MacArthur Foundation. (2023). Circular economy principles: Designing for the future. https://ellenmacarthurfoundation.org

Ferasso, M., Tortato, U., & Ikram, M. (2023). Mapping the circular economy in the small and medium-sized enterprises field: An exploratory network analysis. *Cleaner and Responsible Consumption,* 11, 100149. https://doi.org/10.1016/j.clrc.2023.100149

Ferreira, L. (2024, May). Unravelling the Adoption of Digital Technologies by European SMEs. In *International Conference on Digital Economy* (pp. 22-35). Cham: Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-76365-6_2

Gianaroli, F., Preziosi, M., Ricci, M., Sdringola, P., Ancona, M. A., & Melino, F. (2024). Exploring the academic landscape of energy communities in Europe: A systematic literature review. *Journal of Cleaner Production,* 451, Article 141932. https://doi.org/10.1016/j.jclepro.2024.141932

Gupta, K., Gupta, N., & Goktas, P. (2025). Industrial IoT and Sustainable Development. AI and ML Techniques in IoT-based Communication: *A Path to Sustainable Development Goals*, 147-178. https://doi.org/10.1002/9781394337262.ch07

Huynh, M. S. (2024). Circular economy and digital transformation: Enhancing corporate competitiveness in the market. *European Modern Studies Journal,* 8(3), 27. https://doi.org/10.59573/emsj.8(3).2024.27

Khan, R., & Mihaisi, S. M. K. A. (2023). Promoting circular economy model through SMEs' growth: A focus on African nations. *Journal of Production Operations Management and Economics*. https://doi.org/10.55529/jpome.36.40.52

Khan, S. A., Yu, Z., & Farooq, K. (2022). Green capabilities, green purchasing, and triple bottom line performance: Leading toward environmental sustainability. *Business Strategy and the Environment,* 32(4), 2022–2034. https://doi.org/10.1002/bse.3234

Klimecka-Tatar, D., & Kapustka, K. (2025). The role of artificial intelligence in circular economy strategies: Predictive analysis for SMEs. *Management Systems in Production Engineering,* 33(2), 212–219. https://doi.org/10.2478/mspe-2025-0020

Kochert, R. (2024). Process Digitalization: 3D Deep Learning in Manufacturing Applications (*Doctoral dissertation, Massachusetts Institute of Technology*). https://hdl.handle.net/1721.1/156013

Kumba, H., Makepa, D. C., Charamba, A. N., & Olanrewaju, O. A. (2024). Towards circular economy: integrating waste management for renewable energy optimization in Zimbabwe. *Sustainability*, *16*(12), 5014. https://doi.org/10.3390/su16125014

Mashoko, D. (2025). Disruptive Frugal Digital Technology and Small and Medium Enterprises' Innovation Performance in the Food Sector in Zimbabwe: A Case of SMEs in Masvingo Urban. In Disruptive Frugal Digital Innovation in Africa (pp. 223-243). *Emerald Publishing Limited*. https://doi.org/10.1108/978-1-83549-568-120251013

Mathebula, M. (2022). Urban agriculture, sustainability, and Internet of Things: Applying UTAUT to determine the behavioural intention to use IoT (Doctoral dissertation, University of Pretoria). *ProQuest Dissertations & Theses.* https://doi.org/10.25403/UPresearchdata.22064477

Mrad, M., & Boujelbène, Y. (2025) State-of-The-Art Review: Artificial Intelligence and Robotics for Reducing Carbon Emissions in Supply Chain Management. https://dx.doi.org/10.2139/ssrn.5274912

Muzamwese, T. C., Franco-Garcia, L., & Heldeweg, M. A. (2024). The role of sustainable business networks in promoting a Circular Economy in Africa; A systematic literature review. *Wiley Interdisciplinary Reviews: Energy and Environment*, *13*(1), e506. https://doi.org/10.1002/wene.506

Muzondo, P. J., Mashapure, R., & Masiiwa, S. T. (2025). Barriers and enablers in adopting circular business models in horticulture SMEs: Insights from Zimbabwe. *Journal of Circular Economy,* 3(3). https://doi.org/10.55845/GYQR3716

Muzondo, P. J., Masiiwa, S. T., & Marodza, L. (2025). Digital twin technology in supply chain management: A systematic literature review and future research agenda. *Journal of Emerging Technologies and Innovative Research (JETIR),* 12(7), Article JETIR2507725. https://www.jetir.org/view?paper=JETIR2507725

Muzondo, P. J., Matowanyika, K., & Chipangamate, N. (2025). Integrating IoT in Public Transport Logistics: A Systematic Review of Fleet Management and Safety in Zimbabwe's Supply Chain. *Dibon Journal of Business*, *1*(3), 219-242. https://doi.org/10.64169/djb.117

Natrajan, N. S., Sanjeev, R., & Jain, R. U. (2024). Sustainability in small and medium enterprises: A circular economy approach using cloud computing. *Business Strategy & Development*, *7*(2), e370. https://doi.org/10.1002/bsd2.370

Neri, A., Cagno, E., Susur, E., Urueña, A., Nuur, C., Kumar, V., ... & Sorrentino, C. (2025). The relationship between digital technologies and the circular economy: a systematic literature review and a research agenda. *R&D Management*, *55*(3), 617-713. https://doi.org/10.1111/radm.12715

Omowole, B. M., Olufemi-Philips, A. Q., Ofadile, O. C., Eyo-Udo, N. L., & Ewim, S. E. (2024). Barriers and drivers of digital transformation in SMEs: A conceptual analysis. *International Journal of Frontline Research in Multidisciplinary Studies*, *5*(2), 019-036. https://doi.org/10.56781/ijsrst.2024.5.2.0037

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., ... Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ,* 372, n71. https://doi.org/10.1136/bmj.n71

Peerally, J. A., Santiago, F., Moghavvemi, S., & Marianna, E. T. (2025). Building manufacturing firms' digital technological capabilities for circular economy outcomes in developing and emerging economies. In Building Digital Technological Capabilities (pp. 167-217). *Edward Elgar Publishing*. https://doi.org/10.4337/9781803922362.00013

Pereira, V., Nandakumar, M. K., Sahasranamam, S., Bamel, U., Malik, A., & Temouri, Y. (2022). An exploratory study into emerging market SMEs' involvement in the circular economy: Evidence from India's indigenous Ayurveda industry. *Journal of Business Research,* 142, 188–199. https://doi.org/10.1016/j.jbusres.2021.12.053

Raman, R., Das, P., Aggarwal, R., Buch, R., Palanisamy, B., Basant, T., ... & Nedungadi, P. (2025). Circular Economy Transitions in Textile, Apparel, and Fashion: AI-Based Topic Modeling and Sustainable Development Goals Mapping. *Sustainability*, *17*(12), 5342. https://doi.org/10.3390/su17125342

Rueda, J. (2025). Genetic Enhancement and Technomoral Change: An Anticipatory Ethics Approach. https://doi.org/10.4324/9781003674580

Santos, A. D. M. (2024). Industry 4.0 digital technologies as enablers of sustainability for small and medium enterprises. https://doi.org/10.1108/IJQRM-11-2024-0379

Schröder, P., Albaladejo, M., Ribas, P. A., MacEwen, M., & Tilkanen, J. (2020). The circular economy in Latin America and the Caribbean. *The Royal Institute of International Affairs, Chatham House, London, UK*.https://justtransitionforall.com/wp-content/uploads/2022/10/circular_economy_lac-1.pdf

Singh, S., Yadav, R., & Singh, A. N. (2025). Circular practices in the agricultural sector: current challenges and opportunities. *Circular economy and green transition in the global south: perspectives and prospects*, 169-197. https://doi.org/10.1007/978-3-031-90827-9_7

Soriano-Pinar, I., Díaz-Garrido, E., & Bermejo-Olivas, S. (2023). Digital transformation for a circular economy: Insights from co-word analysis. *The Journal of Technology Transfer*, 1-30. https://doi.org/10.1007/s10961-023-10041-x

Teixeira, E. L. S., Chiaroni, D., Franzò, S., & Pacicco, F. (2022). Transition of manufacturing companies towards circular economy: The enabling role of digital technologies for product life-cycle extension. *Circular Economy Journal.* https://doi.org/10.55845/CGKJ4679

Urbinati, A., Franzò, S., Chiaroni, D., & Pacicco, F. (2022). Transition of manufacturing companies towards circular economy: The enabling role of digital technologies for product life-cycle extension. *Circular Economy Journal.* https://doi.org/10.55845/CGKJ4679