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Research paper

Systematic Literature Review on Circular Economy for Sustainable Growth and Resilience in The Manufacturing Sector in Sri Lanka

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Abstract

This paper presents a systematic literature review (SLR) on Circular Economy (CE) strategies in the manufacturing sector, with a specific focus on their contribution to sustainable growth and resilience. Following PRISMA 2020 guidelines, 259 peer-reviewed publications from seven major databases were screened, resulting in 46 studies that met the inclusion criteria. Bibliometric mapping and thematic synthesis reveal that although CE research is expanding rapidly, only 11% of studies address small and medium-sized enterprises (SMEs) in developing economies. Key strategies consistently highlighted include closed-loop supply chains, eco-design, industrial symbiosis, and product-as-a-service, which demonstrate measurable environmental and economic benefits. However, implementation remains constrained by non-harmonized CE indicators, institutional gaps, and limited digital integration, particularly in Global South contexts such as Sri Lanka. To address these gaps, this paper introduces three strategic contributions: (i) a Circular Economy Maturity Matrix (CEMM) to assess SME progress, (ii) a Policy-Technology Alignment Map linking regulatory instruments with CE practices, and (iii) a set of lightweight CE indicators tailored for SMEs in resource-constrained settings. These tools provide a context-sensitive foundation for bridging CE adoption with systems thinking, resilience engineering, and Industry 4.0 integration. By synthesizing fragmented insights and proposing actionable frameworks, the paper establishes a strategic reference for policymakers, practitioners, and scholars seeking to advance CE-driven resilience in manufacturing, with relevance for developing economies.

Keywords: *Circular Economy; Manufacturing Sector; SMEs; Developing Economies; Resilience; CE indicators; Industry 4.0; Sri Lanka.*

1. Introduction

1.1. Background and importance of circular economy (CE)

The transition from a linear “take-make-dispose” economy towards a Circular Economy (CE) has emerged as a central strategy to achieve sustainable industrial growth and resilience (Geissdoerfer et al., 2017). CE frameworks emphasize resource efficiency, waste minimization, and regenerative loops through recycling, remanufacturing, and eco-design (Bjørnbet et al., 2021). As shown in Figure 1, the linear and circular economic models differ fundamentally in their treatment of material flows and value retention. While the linear model follows a one-way material flow resulting in value loss at end-of-life, the circular model introduces regenerative loops that extend product lifecycles through reuse, recycling, and remanufacturing. Empirical studies reviewed in this paper suggest that firms adopting circular models frequently report reductions in virgin material use (typically 10-20%) and waste-disposal costs (8-15%), particularly in resource-intensive manufacturing sectors (Ghisellini et al., 2016; Lieder & Rashid, 2016; Bjørnbet et al., 2021).

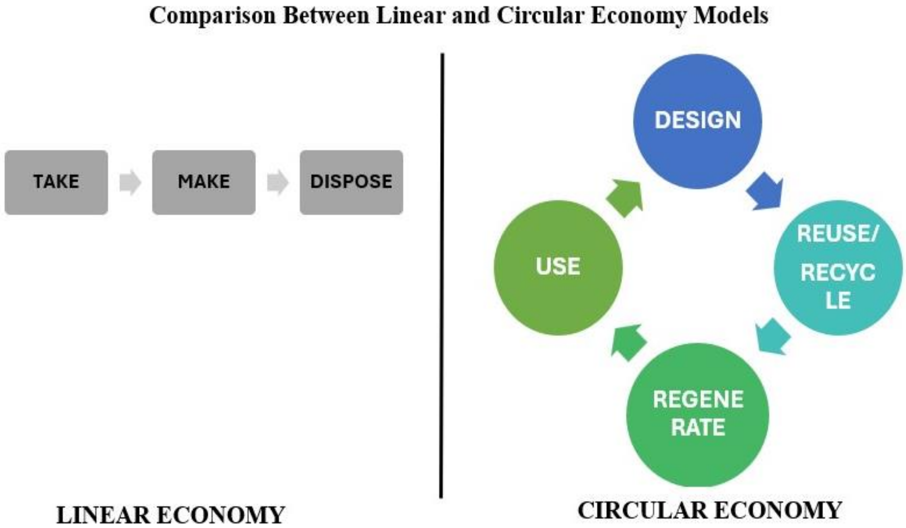

Fig. 1: Comparison between Linear and Circular Economy Models.

A simple schematic contrasting the traditional linear model (Take → Make → Use → Dispose) with the circular model (Design → Use → Reuse/Recycle → Regenerate).
However, while policies articulate high-level objectives, operational tracking systems, CE-specific performance metrics, and SME-oriented implementation strategies remain underdeveloped in Sri Lanka and across the Global South. Achieving For manufacturers, CE provides not only environmental benefits but also competitive advantages through innovation, cost savings, and new business models such as product-as-a-service and industrial symbiosis (Kirchherr, Reike, & Hekkert, 2017; Ghisellini, Cialani, & Ulgiati, 2016). With manufacturing responsible for a significant share of global material consumption and emissions, it is widely regarded as a priority sector for circular transformation (Stahel, 2016). Global policy frameworks, including the European Green Deal and China's Circular Economy Promotion Law, reinforce CE adoption through regulatory and financial mechanisms (European Commission, 2020; Mathews & Tan, 2011). In Sri Lanka, policy interest has grown through the National Industrial Development Strategy (2021-2027), which integrates eco-innovation, resource efficiency, and CE into priority sectors such as manufacturing and agro-processing (Ministry of Industries, 2021), aligning with SDG 9 (Industry, Innovation, and Infrastructure) and SDG 12 (Responsible Consumption and Production) (UNDP Sri Lanka, 2022).
systemic change therefore requires multi-stakeholder collaboration and frameworks that bridge policy ambition with industrial practice (de Jesus & Mendonça, 2018; Korhonen, Honkasalo, & Seppälä, 2018).

1.2. Problem statement

Although CE strategies such as eco-design, closed-loop supply chains, and industrial symbiosis have demonstrated effectiveness in improving sustainability outcomes, their implementation in manufacturing still faces persistent barriers. These include technological limitations, financial constraints, fragmented regulatory frameworks, and organizational inertia rooted in linear production systems (Lieder & Rashid, 2016). Small and medium-sized enterprises (SMEs), which dominate manufacturing in developing economies, encounter additional challenges such as inadequate infrastructure, low awareness, and weak institutional support (Prieto-Sandoval, Jaca, & Ormazabal, 2018).
Compounding these issues is the absence of harmonized CE metrics, which hinders performance monitoring and policy benchmarking across regions (Moraga et al., 2019). While developed economies benefit from structured CE indicators and digital tools, developing economies often lack the resources and capabilities to adapt them effectively. As a result, CE adoption in SMEs within low and middle-income contexts such as Sri Lanka remains fragmented, ad hoc, and poorly documented in the academic literature.

1.3. Research gap

The current CE literature is disproportionately concentrated on large firms in Europe and China, supported by advanced technologies and robust policy frameworks (Bocken et al., 2016; Kirchherr et al., 2017). In contrast, there is limited empirical and conceptual work addressing how SMEs in resource-constrained, Global South economies can operationalize CE principles. Furthermore, few studies integrate CE adoption with broader strategic frameworks such as systems thinking (Meadows, 2008), resilience engineering (Hollnagel et al., 2011), and Industry 4.0 digitalization (Kagermann et al., 2013; Lasi et al., 2014). This lack of integration reduces the practical utility of CE research for policymakers and practitioners seeking context-sensitive solutions.
In summary, three key gaps are evident:
1) Underrepresentation of SMEs and developing economies in CE research.
2) Lack of standardized, lightweight CE metrics applicable in resource-constrained contexts.
3) Insufficient integration of CE with resilience and Industry 4.0 frameworks, limiting its strategic positioning.

1.4. Strategic theoretical foundations

The CE adoption within the manufacturing sector is not only a technical shift but it is the change that can be strategic with regard to broader theoretical frameworks. Putting CE into context with respect to well-defined strategic paradigms e.g., systems thinking, resilience engineering, and the industry 4.0 evolutionary model, permits a more purposeful and forward-looking examination.
System Thinking
CE can also be viewed as a system-level intervention that attempts to reengineer industrial metabolism where linear processes are redesigned to form regenerative cycles. System thinking allows to understand interdependence of materials, technology, policy, and organization behavior and can help identify better points of leverage to drive circular transition. Interventions grounded in systems thinking can yield sustained transformation by addressing root causes rather than symptoms (Meadows 2008).

Resilience Engineering

This theoretical stream examines how systems maintain operational continuity and recover from disruptions. In the CE scenario, resilience engineering offers a way of understanding how circular approaches like remanufacturing, closed-loop distribution chains, and just-in-time tracking can make the supply chains more flexible and robust. Such strategies are especially critical to manufacturing activity in developing economies subject to greater levels of resource volatility and political uncertainty (Hollnagel et al., 2011).

Industry 4.0 Evolutionary Model

The convergence of CE and Industry 4.0 technologies and tools like IoT, blockchain, and AI have created smart manufacturing processes, which can optimize circularity. These technologies make it easier to track lifecycles, predictive maintenance and optimization of resource loops. This is described in the Industry 4.0 evolution model (Kagermann et al. 2013) and (Lasi et al. 2014), a progressive line of movement of industry towards an automatized state to a cognitive state. Digitalization is no longer only an auxiliary technology but a strategic enabler of circular change.

1.5. Research objectives

In this study, the following objectives are sought:

- Objective 1: To synthesize the available academic and policy literature on CE to determine and evaluate CE strategies in the manufacturing sector critically.
- Objective 2: To Investigate the most important drivers, barriers and enablers of implementation of CE practices in various industrial and geographical settings.
- Objective 3: To Understand how the connection between CE practices and sustainability outcomes manufacturing has been conceptualized.
- Objective 4: To Determine knowledge gaps in the literature and give strategic research recommendations to researchers, practitioners, and policy makers with priority given to Sri Lanka.

1.6. Research questions

Aligned with these objectives, the study is guided by the following research questions:

- RQ1: Which CE strategies have been suggested and applied in the manufacturing sector to support sustainable growth and resilience?
- RQ2: How do existing studies conceptualize the relationship between CE practices and sustainability outcomes in manufacturing?
- RQ3: What are the key barriers and enablers of CE adoption identified in the literature?
- RQ4: What knowledge gaps and future directions are proposed for introducing CE principles into resilient manufacturing development, particularly in developing economies?

2. Methodology

2.1. Review design

In this research, a qualitative systematic literature review (SLR) serves as a method of synthesizing and critically reviewing literature that has been researched about strategies in circular economy (CE) within the manufacturing sector, and where focus has been primarily on sustainable growth and resilience. The review does not put emphasis on statistical aggregation; rather, interpretation-based thematic analysis is reported with the aim of identifying the patterns and structures of concepts. The procedures are guided by Tranfield, Denyer, and Smart, (2003) and transparent, rigorous, and replicable since they follow the PRISMA 2020 guidelines.

The review stages included the following four stages:

1) Formulation of research questions
2) Development of search strategy and selection criteria.
3) Quality screening and quality assessment
4) Thematic synthesis of findings

As illustrated in Figure 2, the systematic literature review was structured as a sequential and iterative research framework aligned with PRISMA 2020 guidelines. The framework visually integrates the four core stages of the review process research question formulation, search and screening, quality appraisal, and thematic synthesis ensuring methodological transparency and logical progression. By explicitly linking database identification, inclusion-exclusion filtering, and synthesis activities, the framework supports replicability and reduces procedural ambiguity, which is critical for evidence-informed research in Circular Economy studies.

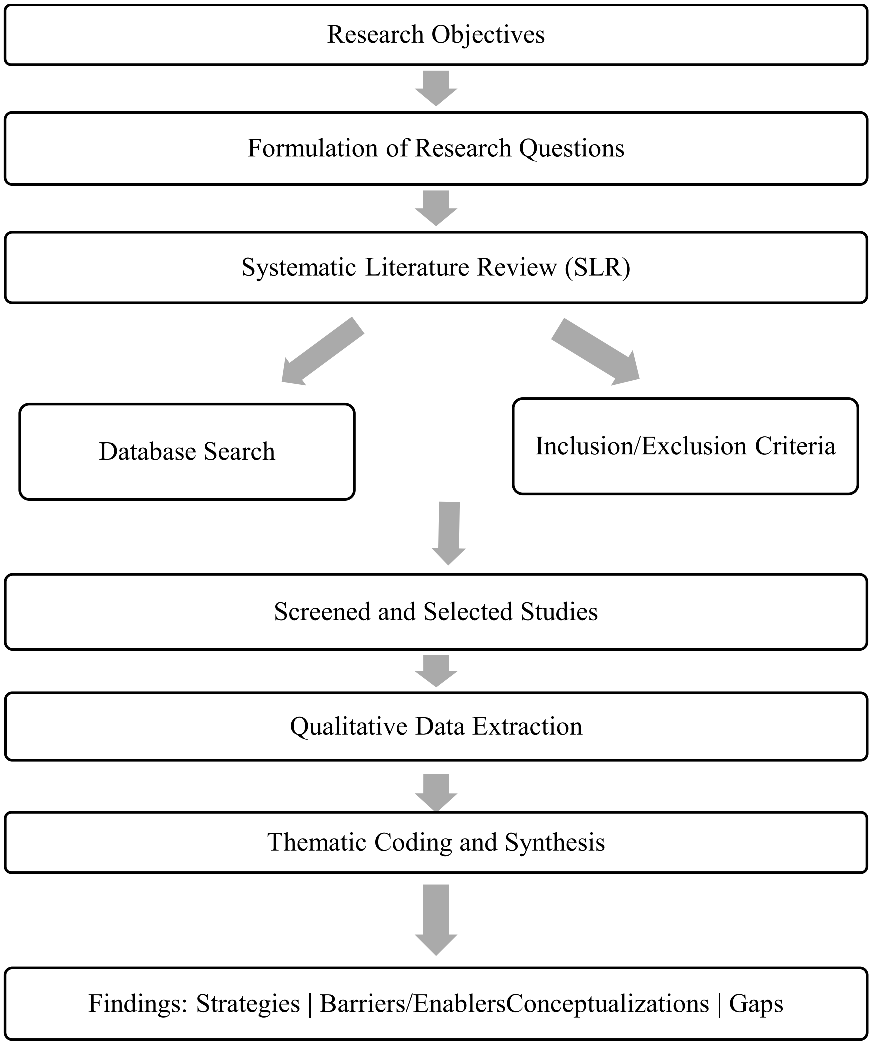

Fig. 2: Structured Research Framework Illustrating the Sequential Stages of the PRISMA Guided Systematic Literature Review Process.

2.2. Search strategy and databases

The search was done thoroughly through Scopus, Web of Science, ScienceDirect, Emerald Insight, SpringerLink, Taylor and Francis, and Google Scholar. Using keywords and the Boolean operators, the search strategy has been combined as shown:
(circular economy" OR "CE") AND (manufacturing" OR "industry") AND ("sustainability" OR "resilience")
Parameters applied:

- Journal articles with peer reviews in a period between 2010 and 2025
- Online publications in English
- Specialization in manufacturing CE uses

Reviewing of key articles through use of snowballing techniques was also applied. To start with, 259 articles were found. Upon the identification and elimination of duplicates and the following of the screening criteria, the final list of 46 articles was revealed to be reviewed.

2.3. Inclusion and exclusion criteria

A predetermined inclusion and exclusion criteria were used to guarantee the quality, relevance and rigor of literature to be included in this review. These criteria are aligned with established practices in systematic literature reviews (Tranfield et al., 2003; Snyder, 2019) and are intended to filter studies that specifically address the implementation of Circular Economy (CE) strategies within the manufacturing sector. The research that was emphasized in terms of discussing the issues of sustainability, resilience, and resource efficiency as major themes and approaches sharing the same vision as that of Sri Lanka in terms of the policy direction and industrial development plans (Korhonen et al., 2018). There is also a specific set of the selection regarding the peer-reviewed journal articles published in English in 2010-2025 that help to get a contemporary and geographically diverse picture, however, remain relevant to the situation of developing economies.

2.3.1. Inclusion criteria

- Peer-reviewed journal articles as regards CE strategies in the manufacturing industry
- Articles on the issues of sustainability, resilience, or resource efficiency
- Studies done either in other countries or in the developing economy, and specifically in Global south on Publications 2010- 2025
- Publications issued in English language

2.3.2. Exclusion criteria

- Conference proceedings, editorials and grey literature
- Research which does not particularly deal with the manufacturing applications of CE
- Pieces that lack their methodological base Duplicates or unreadable full texts
- Publications other than English

2.4. Data extraction and synthesis

A uniform data extraction procedure was adopted to ensure structured and clear evaluation of the chosen literature. This approach is consistent with best practices in systematic literature reviews, enabling the synthesis of heterogeneous research findings across diverse contexts (Boell & Cecez-Kecmanovic, 2015; Petticrew & Roberts, 2006). It was found that key variables are needed to embrace the most necessary aspects of every study in terms of authorship, geographic and industrial focus, research design, and the main thematic information. There was a special focus of extracting information that pertained to Circular Economy (CE) strategies, the observance of barriers, enablers, and sustainable/resilience outcomes that were identified as relevant factors in informing CE implementation as applied in developing economies with their manufacturing industry as in the case of Sri Lanka. Alongside, data was extracted followed by the undermentioned factors.

- The name of the author, year, and the publication source
- Region emphasis and industrial setting
- Research methodology
- CE approaches or models considered
- Determined impediments and facilitators
- Sustainability and resiliency outcomes

Thematic coding approach was used to combine the retrieved data into some larger categories and patterns that allowed assessing the conceptual and theoretical contribution of literature critically.

2.5. Quality appraisal and risk of bias assessment

To enhance methodological consistency and transparency, a formal quality appraisal was conducted for the 46 studies included in the synthesis. Given the methodological diversity of the evidence base, we applied the Mixed Methods Appraisal Tool (MMAT, 2018), which supports appraisal across qualitative, quantitative, and mixed methods designs.

Each study was assessed against five MMAT criteria relevant to its design (e.g., clarity of research questions, appropriateness of data collection, coherence between data and interpretation, and robustness of analysis). Studies were categorized as high quality (≥4 criteria met), moderate quality (3 criteria), or lower quality (≤2 criteria). Lower-rated studies were retained only when they contributed unique contextual insights (e.g., SME evidence from developing economies) and were weighted cautiously during thematic synthesis.

Risks of bias were most associated with limited generalizability of single-case studies, reliance on self-reported sustainability performance, and publication bias toward positive CE outcomes. Incorporating this appraisal strengthens the credibility of cross-study comparisons and reduces interpretive bias in the final synthesis.

Figure 3 presents the PRISMA 2020 flow diagram summarizing the identification, screening, eligibility assessment, and inclusion of studies in this systematic literature review. Of the 259 records initially identified across seven databases and supplementary sources, 46 studies met all inclusion criteria and were retained for final synthesis, representing approximately 18% of the original dataset. The structured screening process incorporating duplicate removal, title and abstract screening, and full-text eligibility assessment enhances transparency and minimizes selection bias, thereby strengthening the robustness of the evidence base used in this review.

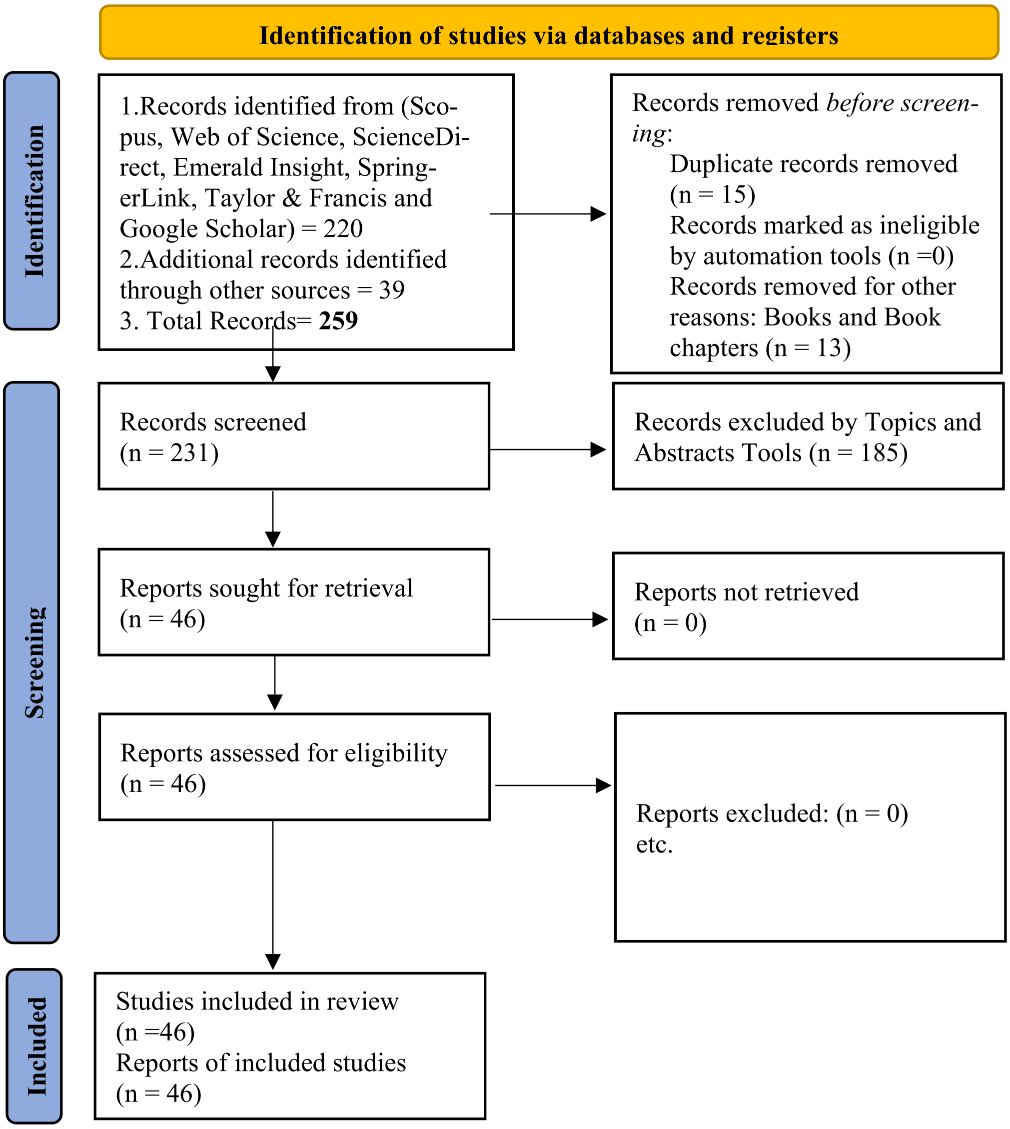

Fig. 3: PRISMA 2020 Flow Diagram Summarizing the Selection and Screening Process.

3. Results

3.1. Bibliometric and mapping analysis

To have a more sophisticated overview of the research field, bibliometric analysis was done on the complete collection of 259 papers found as a result of the systematic search. This part shows the descriptive statistics, publication trends and the intellectual architecture of the field.

3.1.1. Year wise publication trends

Figure 4 illustrates the year-wise distribution of publications on Circular Economy in the manufacturing sector between 2010 and 2025. The figure shows a modest level of scholarly output prior to 2016, followed by a pronounced acceleration after 2017. Notably, more than 60% of the total publications were produced during the period 2017-2025, coinciding with the global diffusion of the Sustainable Development Goals and the emergence of major policy initiatives such as the European Green Deal. This trend reflects the growing recognition of Circular Economy as a strategic framework for sustainability and industrial resilience.

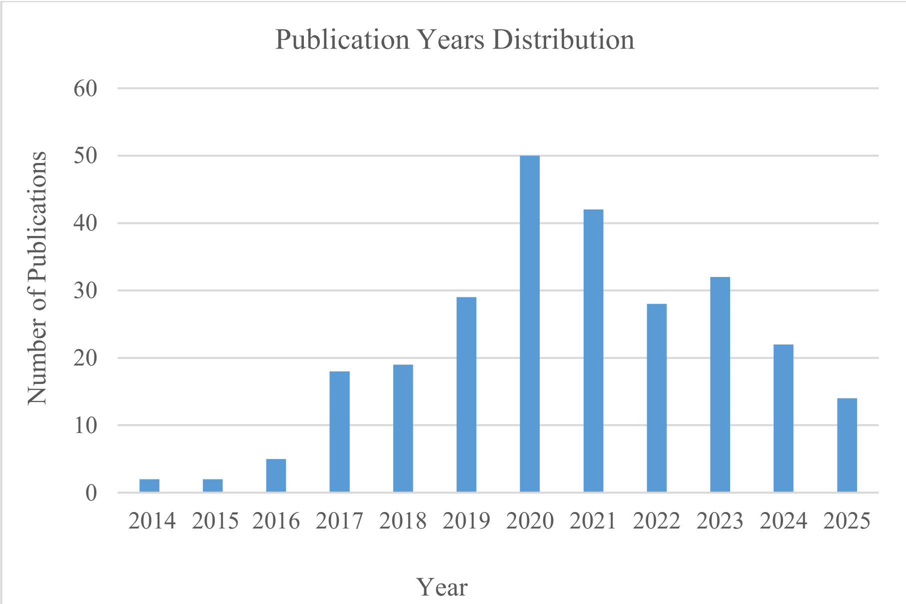

Fig. 4: Number of Publications Per Year (259 Papers).

3.1.2. Country-wise distribution

Most of the publications were by European and specifically EU-based nations, then China, Japan, the United States and the emerging economies such as India and Brazil. There was low representation by developing countries like Sri Lanka which were beginning to multiply in the recent years.

3.1.3. Top authors and journals

Those who authored the most in CE in manufacturing were Author Vitolla, Filippo (29 papers), Author Ramio, Nicola (27) and Author LAbate, Vitiana (20). The journals with the greatest impact ruled the publishing field, with the Journal of Cleaner Production (28 papers), Sustainability (13), and Business Strategy and the Environment (10) being the major ones.

Figures 5 and 6 provide a bibliometric overview of the most influential contributors and publication outlets in Circular Economy research within the manufacturing sector. Figure 5 highlights a concentration of scholarly output among a small group of authors, indicating the presence of core research clusters that have played a significant role in shaping theoretical frameworks and empirical inquiry. Figure 6 demonstrates that high-impact journals such as the Journal of Cleaner Production, Sustainability, and Business Strategy and the Environment dominate the dissemination of CE research, reflecting the interdisciplinary convergence of environmental science, operations management, and sustainability-oriented business strategy.

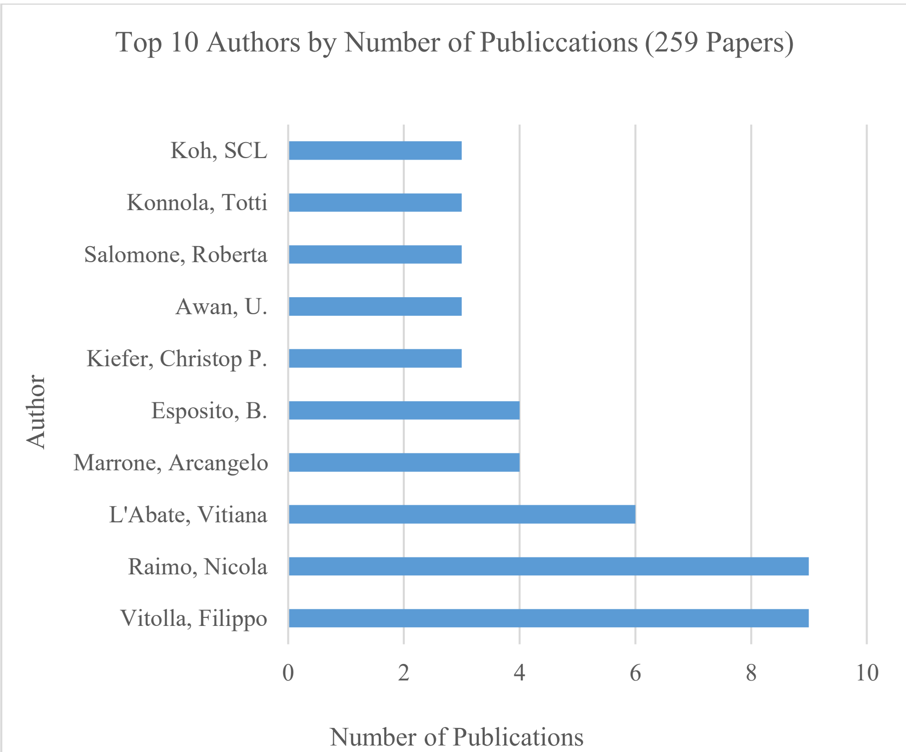

Fig. 5: Top 10 Authors by Number of Publications in Circular Economy Manufacturing Research (N = 259).

Fig. 6: Top 10 Journals Publishing Circular Economy Research in the Manufacturing Sector.

3.1.4. Keyword co-occurrence analysis

Figure 7 visualizes the co-occurrence network of keywords in the selected Circular Economy manufacturing literature using VOSviewer software. The network highlights circular economy as the dominant central node, closely connected to themes such as sustainability, life-cycle assessment, innovation, and industrial symbiosis. The identified clusters demonstrate the interdisciplinary structure of the field, linking environmental, technological, and managerial perspectives. Notably, emerging and comparatively underrepresented themes including resilience, bioeconomy, and degrowth appear at the periphery of the network, indicating potential directions for future research and conceptual development.

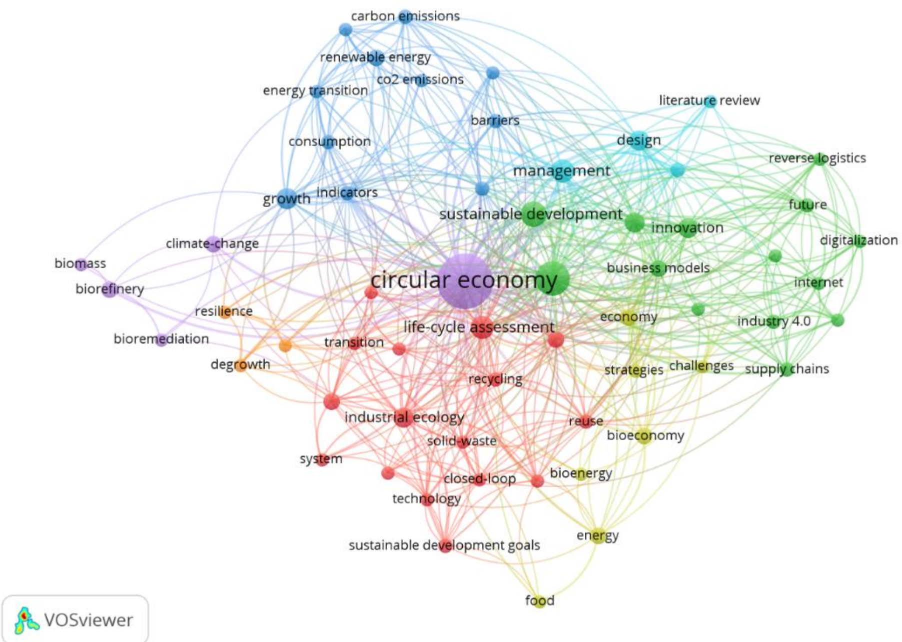

Fig. 7: Vosviewer-Based Keyword Co-Occurrence Network Illustrating Thematic Clusters in Circular Economy Manufacturing Research.

3.1.5. Co-authorship networks

Figure 8 presents the co-authorship network visualization of Circular Economy research in the manufacturing sector, generated using VOSviewer. The network reveals distinct clusters of closely collaborating authors, indicating the presence of established research groups that drive theoretical development and empirical inquiry in the field. The size and connectivity of nodes suggest that a relatively small number of author groups contribute disproportionately to the CE knowledge base, while limited cross-cluster connections highlight opportunities for greater interdisciplinary and cross-regional collaboration, particularly involving researchers from developing economies.

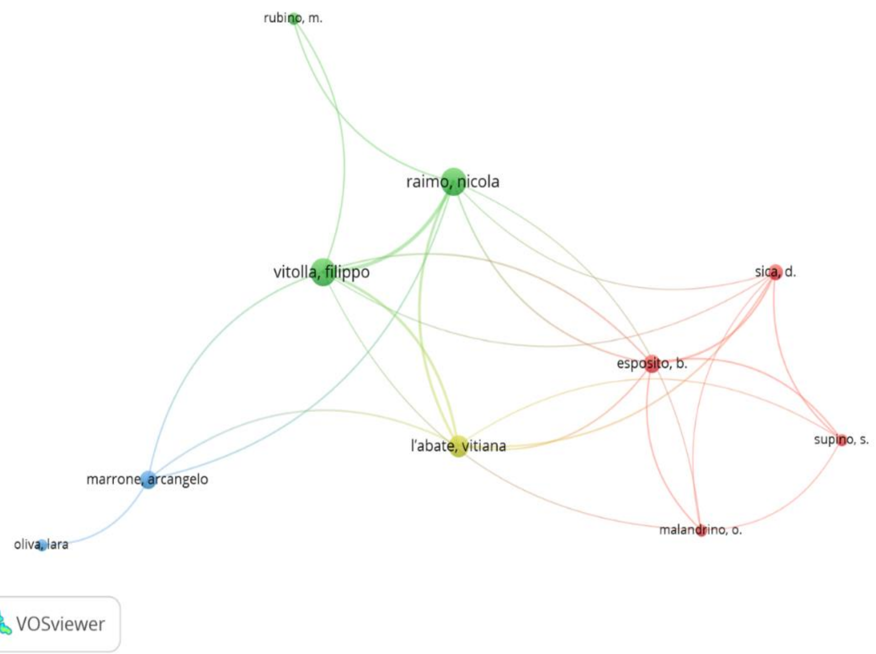

Fig. 8: Vosviewer-Based Co-Authorship Network Illustrating Collaboration Patterns in Circular Economy Manufacturing Research.

This network defines the individual authors as the nodes of the network, where the size of node is proportional to the number of publications or the relative impact of the author in collaborative environment. The edges (connecting lines) denote co-authors relationships, which reflects the cases of scholarly collaboration between and among the institutions and the regions. With colored clusters, it is shown that there are subgroups of authors who regularly work together, and this indicates the structure of research collaboration in the area. The green cluster, to give an example, is a core worked-at group around Nicola Raimo, Filippo Vitolla and Vitiana LAbate. The blue group is on the anchors of Arcangelo Marrone and partners whereas the red group is on the anchors D. Sica, B. Esposito, O. Malandrino, and S. Supino. Such clusters underline the role of interdisciplinary and cross-border alliances in the development of circular economy scholarships.

3.2. Qualitative synthesis of final papers

In this part, there is the thematic synthesis of the remaining 46 papers chosen following the PRISMA screening. The synthesis will be divided into six sub-sections that include: a summary of the selected studies, methods applied, circular economy (CE) strategies discussed, sector and geographical focus, research gaps and future possible research directions, main findings.

3.2.1. Overview of selected studies

The last group of 46 articles includes the period between 2010 and 2025 and covers a wide scope of research settings, mainly oriented to manufacturing industries. Europe, China, and the United States give rise to most of the study, though more emerging work is coming in the developing areas such as India, Vietnam, and Indonesia. Although the study in Sri Lanka itself is limited compared to the existing studies of similar economies, a few publications can provide the study with relevant information regarding the country. The publications span many areas of manufacture each with a focus on electronics, automotive, textile, food processing and building material industries. The research can be limited to one firm, can be cross-sectoral, or multi-countrywide.

3.2.2. Methodologies used in selected papers

The methodological traditions assumed in the course of the chosen researches demonstrate the combination of qualitative, quantitative, and conceptual orientations. A breakdown features:

- Case Studies (Approx. 40%): To offer analytical talk of CE carried out at companies or clusters.
- Conceptual and Theoretical Papers (25%): Provision of frameworks, models or typology to inform CE practices.
- Empirical Surveys and Interviews (20%): Gathering the stakeholder views in considering the usage of CE.
- Mixed-Methods Studies (10%): qualitative and quantitative methods are brought together.
- Literature Reviews/Meta-Analyses (5%): There are synthesis of past studies or bibliometric information.

This methodology shows that there is prevalence of applied methodologies and exploratory designs which are supposedly meant to identify either the barriers or facilitating factors to CE implementation in the real world.

3.2.3. CE strategies and frameworks addressed

More recent SME-focused studies (2024-2025) indicate that Industry 4.0 acts as a conditional enabler of circularity: the highest marginal gains are often achieved through low-cost, scalable digital tools (e.g., cloud-based ERP modules, QR-enabled material tracking, and predictive-maintenance analytics) rather than capital-intensive automation (OECD, 2024; Saari et al., 2024). This supports the view that CE-I4.0 integration in developing economies should prioritize minimum viable digitalization that strengthens traceability, resource monitoring, and reverse-logistics coordination.

The recognized approaches to CE that apply to the manufacturing setting are regularly discussed and examined in the studies. Repeated tactics are:

- Closed-loop supply chains - facilitating the usage of material reuse, remanufacturing and recycling.

- Eco-design and sustainable product development - takes the idea of lifecycle thinking to incorporate it into design processes.
- Industrial symbiosis- facilitating depths of resources among firms.
- Product-as-a-Service (PaaS) - transforming owner-centered systems to service-based systems.
- Digital Enablers- including IoT, blockchain, and AI to optimize and track in real-time.

Such strategies are usually to be incorporated in sustainability frameworks such as Lean, Green Supply Chain Management (GSCM), and Life-Cycle Assessment (LCA), which are representative of integrative and system-thinking.

Figure 9 presents a radar chart illustrating sectoral readiness for the integration of Circular Economy practices with Industry 4.0 technologies in manufacturing. Visualization indicates higher readiness levels for digital functions related to monitoring, traceability, and data integration, while more advanced automation and analytics exhibit comparatively lower maturity, particularly among SMEs. This pattern supports the argument that incremental, low-cost digital interventions such as cloud-based ERP modules, QR-enabled material tracking, and basic predictive maintenance tools offer the most feasible and impactful pathway for enhancing circularity in resource-constrained manufacturing contexts.

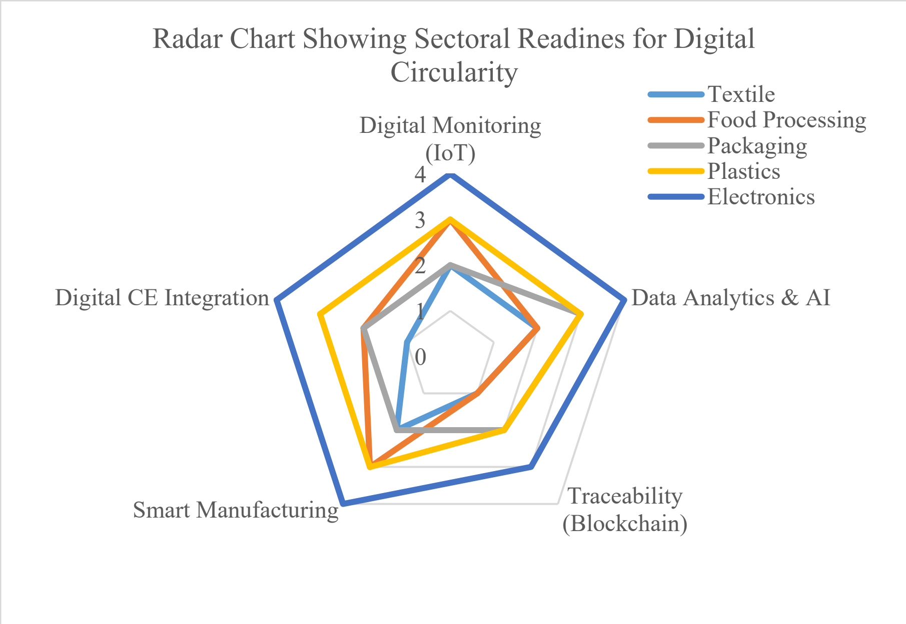

Fig. 9: Radar Chart Illustrating Sectoral Readiness for Integrating Circular Economy Practices with Industry 4.0 Technologies in Manufacturing.

3.2.4. Sectoral and regional focus

Although research is diversified on a global scale, there are certain regional factors that this research reveals:

- Europe: The focus is on digitalization, regulatory frameworks and eco-design complex.
- Asia (China, India, Southeast Asia): Fostering industrial symbiosis, waste valorization and integration of informal sector.
- Latin America & Africa: Less represented, but up and coming, concentrating on low-tech strategies of CE and policy adaptation.

To consolidate regional variations, the following matrix summarizes the dominant CE strategies by region along with contextual notes:

Table 1 compares dominant Circular Economy strategies across regions and highlights contextual differences in policy support, technological readiness, and institutional maturity. The comparison shows that regions with strong regulatory frameworks and digital infrastructure (e.g., Europe and China) emphasize eco-design and circular manufacturing at scale, whereas developing economies rely more heavily on industrial symbiosis and incremental circular practices. This contrast underscores the importance of context-sensitive CE frameworks for SME-dominated economies such as Sri Lanka.

Table 1: Region-Strategy Matrix of CE Adoption in the Manufacturing Sector

Region	Dominant CE Strategy	Notes
Europe	Eco-Design, Industry 4.0	Strong policy support and digital integration
China	Recycling Systems, Circular Manufacturing	Driven by national mandates and investment policies
India	Industrial Symbiosis	Cluster models supported by local government programs
Vietnam	Eco-Innovation, CE Startups	Public-private pilot projects in key urban industries
Sri Lanka	Early-stage awareness, Policy Gap	Fragmented CE adoption, potential via SMEs

3.2.5. Identified gaps and future research directions

Although there is increasing interest in research about the topic, knowledge gaps exist:

- Insufficient empirical data in the developing economies, particularly in small and medium enterprises (SMEs) in low-income countries.
- Lack of longitudinal research in determining the long-term sustainability and resilience success of CE strategies.
- They are not standardized CE measures, and thus cross-study comparisons and policy benchmarking is a challenge.
- Under-researched behavioral as well as institutional criteria, viz. consumer acceptance, cultural norms and inter-organizational collaboration.
- Scanty seeing in SMEs of CE and digitalization, in spite of the fact that the whole world is shifting towards Industry 4.0.

The future studies based on the consideration of context-specific frameworks, localized quality indicators, and multi-stakeholder implementation models should mirror developing economy realities.

3.2.6. Key findings and outcomes

Through synthesis, it emerges that CE strategies have several co-benefits to the manufacturers and these include:
- Environmental benefits: Efficiency in resource use, minimized waste, as well as emissions.
- Economic consequences: Value preservation, cost savings and revenue diversification.
- Increased resilience: Increasing supply chain flexibility, risks mitigation, and thorough running.

Nonetheless, the prescription of effective CE application is associated with institutional fit, leadership support, coordination of stakeholders, and facilitating policy environments. Research highlights that CE works best as a comprehensive change approach besides a bundle of practices.

Figure 10 synthesizes the relationship between Circular Economy strategies, systemic resilience, and innovation cycles within manufacturing systems. The figure illustrates how core CE practices such as eco-design, closed-loop supply chains, industrial symbiosis, and product-as-a-service contribute to sustainability outcomes through resource efficiency and waste reduction, while simultaneously strengthening resilience by enhancing supply chain flexibility and adaptive capacity. The integration of Industry 4.0 technologies enables feedback loops that support continuous learning and innovation, reinforcing the view of CE as a dynamic socio-technical system rather than a static set of environmental practices.

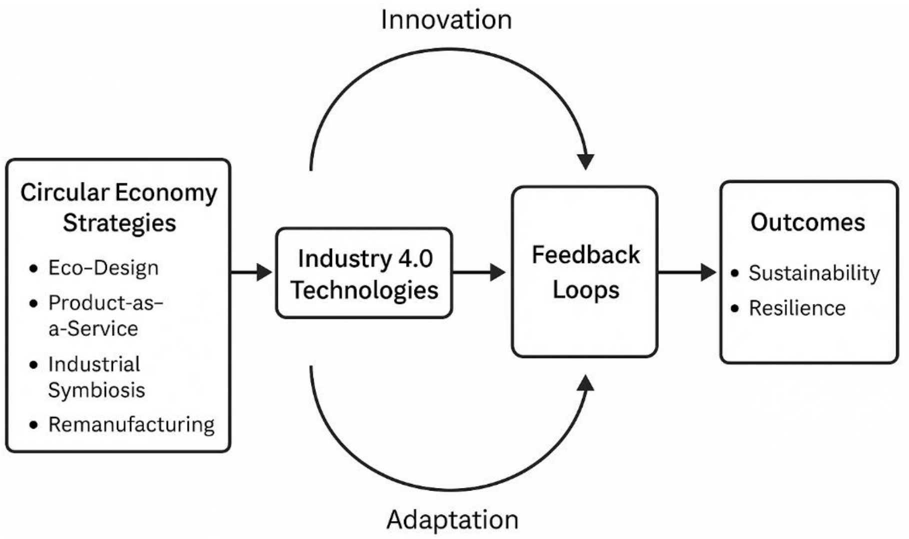

Fig. 10: Conceptual Alignment of Circular Economy Strategies with Systemic Resilience and Innovation Cycles in Manufacturing Systems.

This conceptual diagram illustrates how CE strategies can fit within a systemic resilience and innovation cycles with the integration of Industry 4.0 technologies and feedback system. CE strategies such as eco-design, product-as-a-service, industrial symbiosis, and remanufacturing (Bocken et al., 2016; Ghisellini et al., 2016) form the foundation for transforming traditional manufacturing systems.

These strategies are enabled by digital technologies including the Internet of Things (IoT), blockchain, and artificial intelligence embedded within the Industry 4.0 framework (Kagermann et al., 2013; Lasi et al., 2014), which supports real-time data flows, transparency, and process optimization across the value chain.

The presence of feedback loops reflects the systems thinking perspective, where interdependencies between design, production, and consumption are continuously monitored and adapted (Meadows, 2008). This dynamic interaction creates a reinforcing cycle of innovation (driven by technological evolution) and adaptation (driven by system learning), resulting in improved sustainability outcomes (e.g., resource efficiency, waste reduction) and enhanced resilience (e.g., supply chain robustness, shock absorption) (Hollnagel et al., 2011; Kennedy & Linnenluecke, 2022).

This integrated model demonstrates CE as a cyber-physical and socio-technical evolution rather than a static strategy, capable of driving transformative change in manufacturing systems.

3.3. Barriers and enablers of CE adoption

Common barriers identified include:
- Limitation of technology (e.g. incompetent recycling system)
- Limited financial capacity, i.e. SMEs the regulatory uncertainty or unfriendliness of policy
- Resistance in culture and low consumer awareness
- Lack of standardised CE measurements

Key enablers found across studies:
- Policy framework and government incentive systems (e.g., extended producer responsibility)
- Academic/cross value chain cooperation
- Commitment of leadership and sustainability vision
- Circular design Knowledge and technical expertise availability
- Combining digital and data-based tools

3.4. Case examples relevant to Sri Lanka and similar economies

The specific studies concerning Sri Lanka are scarce; however, there are similar scenarios with other countries, such as India, Vietnam, and Indonesia, that can be transferred to Sri Lanka. These include:
- Cluster models of industrial symbiosis in Indian SMEs

- The inclusion of eco-innovation incentives via the use of public-private partnerships in Vietnam
- Circular textiles and waste-to-resource in Indonesia

These examples show that CE in Sri Lanka can be replicated by frontal policy action, stakeholder awareness, and investment in capacity building.

Table 2 summarizes selected global Circular Economy initiatives and assesses their relevance to the Sri Lankan manufacturing context. The examples illustrate how policy-supported pilot programs, industrial symbiosis clusters, and sector-specific recycling initiatives can be adapted to Sri Lanka's SME-dominated industrial structure. These cases demonstrate that scalable CE adoption does not require high-tech replication but rather contextual adaptation and institutional coordination.

Table 2: Global Circular Economy Initiatives and Their Relevance to Sri Lanka

Country	CE Initiative	Relevance for Sri Lanka
India	SME industrial symbiosis clusters	Replicable among Local SMEs
Netherlands	Circular city frameworks	Guidance for urban policy planners
Indonesia	Textile-to-textile recycling pilots	Similar informal sector structure

These international case examples highlight scalable, policy-supported CE applications that can inform Sri Lanka's transition, particularly in SME clusters, urban planning, and informal sector integration.

4. Discussion

4.1. Critical analysis of key findings

The systematic review indicates an increasing knowledge base for the introduction of CE strategies in the manufacturing sector. The literature on CE is centered on developed economies, in which high technologies, consistent policy environments, and institutional support are drivers of increasing CE implementation. Nevertheless, despite such backgrounds, there are still issues with respect to scalability and standardization of CE practices. Although the literature examined has mentioned closed-loop systems, eco-design, and digital innovation as the effective strategy of CE, there should be a lack of research in the evaluation of CE in real economies and its vast economic benefit and downstream environmental outcome, particularly in small and medium-sized enterprises (SMEs). Moreover, significant material deficit exists in literature addressing performance measures that are extremely thorough to measure circularity in terms other than recycling rates or waste reduction.

4.2. Theoretical and practical implications

The outcomes of the reviewed study have valuable theoretical implications regarding the future CE in manufacturing industry since they point to its shift in the paradigm of waste minimization towards something more comprehensive in terms of sustainability and resilience. The combination of concepts like supply chain resilience and digitalization as well as systems thinking with CE results in a more mature academic discourse that both bridges and links the green and competitiveness agendas. Theoretically, it was noted that the studies reviewed uphold the theoretical stance that CE is no longer restricted to end-of-pipe solution, but it has extended its reach to include measures of eco-design, servitization, and closed-loop systems which are alternatives that disrupt traditional and historical production-consumption models. The increasingly common pairing of CE with sustainability science, industrial ecology and innovation theory is also able to testify to its burgeoning interdisciplinarity. On the operational level, CE provides the manufacturers with actual opportunities to increase resources efficiency, minimize the costs of operations and boost supply chain resilience especially topical with the global upset recently with COVID-19 and the climate-driven threat. Not only the firms following CE strategies, like industrial symbiosis or circular business models, attain the benefits of achieving environmental performance, but also generate a previously untapped source of revenue, and differentiate their products or services in the market. To the practitioners, the review helps to strengthen the argument that practitioners should see CE as a strategic step to innovate rather than a compliance requirement. But participation in these benefits relies on domestic capabilities, stakeholder actions, digital layout, and policy coordination.

Figure 11 illustrates a feedback loop model linking Circular Economy strategies with resilience outcomes in manufacturing systems. The model demonstrates how circular practices such as improved resource efficiency, digital monitoring, and waste reduction generate adaptive supply chain capabilities that enhance system robustness and shock absorption. These resilience outcomes, in turn, reinforce further circular innovation through continuous feedback and learning, highlighting the mutually reinforcing relationship between Circular Economy implementation and long-term manufacturing resilience.

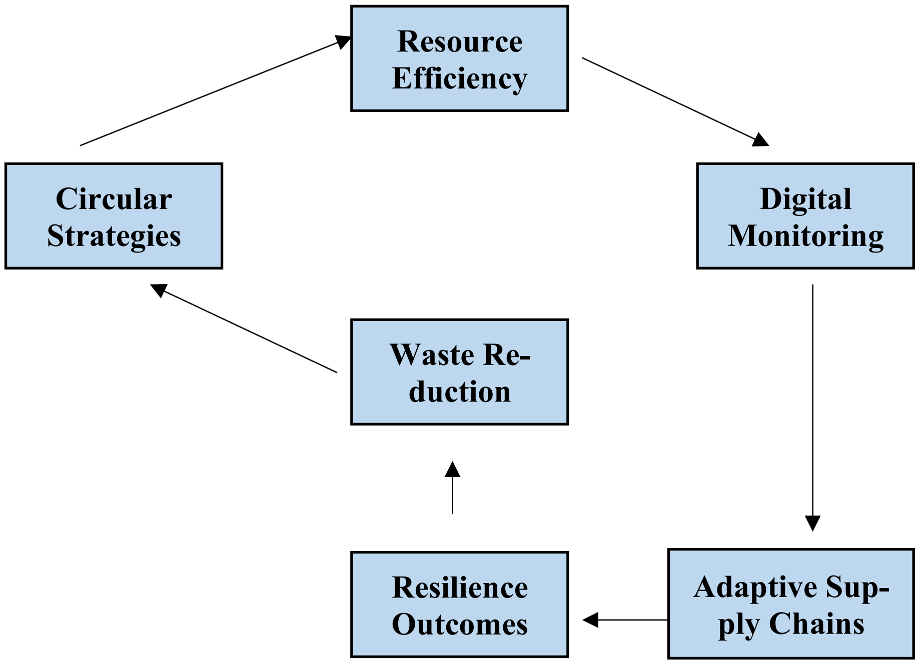

Fig. 11: Feedback Loop Model Illustrating the Reinforcing Relationship Between Circular Economy Strategies and Resilience Outcomes in Manufacturing Systems.

4.3. Research gaps and agenda

There are still many research gaps to be filled, despite the growing literature, suggesting that further research is indeed needed in the form of more empirical, contextual and interdisciplinary exploration:

- Lack of representation of SMEs and developing countries: There is already extensive research on the large manufacturers in Europe and China but little research about the adoption of CE in SMEs and other low and middle-income economies like Sri Lanka. The next research directions should discuss the influence of institutional voids, infrastructure constraints, and cultural factors in adopting CE.
- Absence of longitudinal evaluation of effect: The absence of long-term measurement regarding the long-term nature of environmental and economic effects due to CE system interventions is seen. Further research is necessary to examine the sustainability of CE outcomes in the long term, and how they fare under market shocks and supply chains.
- Requirement of standardization of CE performance measures: There is a lack of standardized measurements to determine circularity within companies and across sectors in current literature. It will be a priority to develop CE metrics that become universally acceptable and capture the input/output efficiency and systemic outcomes.
- Paucity of behavioral and socio research: There is a lack of research on consumer behavior, workforce readiness and organizational culture. Comprehending the social aspect of circularity is essential to incorporating CE into everyday practices and market processes.
- Digital CE enablers in emerging economies: Despite the mention of technologies, such as IoT, AI and blockchain, in CE sources, little is known about their usefulness and adaptability in low-resource manufacturing environments. Research should determine the practicality of adaptation of digital tools in the developing countries.

These gaps would be an obvious outline of future research, policy-relevant, and industrially implementable. Comparative case studies, stakeholder-based frameworks and systems-based models that show the real situation of complexities should be focused on.

4.4. Limitations of the study

Although this review is performed according to a stringent systematic technique and provides a thorough synthesis, some limitations need to be mentioned:

- Database and language restrictions: The review has been limited to English-language journal articles that are peer-reviewed. This meant that related studies could have been omitted on account of use in another language or perhaps format (e.g. technical report, thesis).
- Possible publication effect: A study in which the CE was positive had a greater probability of being published, and this may skew the insights. This could lead to reporting of inaccurate fewer failures or unintended consequences in the implementation of CE.
- Emphasis on manufacturing: Whereas the range covered was purposely limited to manufacturing, there are also appropriate CE strategies in other sectors (e.g., agriculture, urban planning) that could possibly provide lessons that would transfer to the manufacturing environment but that were not noted.
- Incomplete full-text access to all possibly relevant sources: There were a few excluded articles because they had limited access, and this might have limited the breadth of the theme covered in the synthesis.

These limitations will be possible to overcome with future reviews by searching grey literature, increasing linguistic coverage, and triangulating both perspectives of the review, quantitative and qualitative as well as policy perspectives.

4.5. Relevance to policy and industry in Sri Lanka

Recent Sri Lanka-specific evidence (2024-2025) reinforces the barriers identified in this review, particularly in export-oriented manufacturing. Studies focusing on apparel and textiles highlight persistent challenges in post-consumer segregation, limited domestic fiber-to-fiber recycling capacity, and compliance-related cost pressures for SMEs supplying global value chains (Fernando et al., 2024; UNIDO Sri Lanka, 2025). At the industrial-cluster level, preliminary assessments of circularity-related performance in major zones (e.g., Biyagama) suggest progress in energy and water efficiency initiatives, but slower advancement in material circularity due to limited inter-firm material exchange and weak digital traceability (Board of Investment Sri Lanka, 2024). These observations strengthen the case for lightweight CE indicators and staged maturity pathways tailored to resource-constrained SMEs.

The manufacturing sector in Sri Lanka mainly consists of the SMEs and the export-oriented industries in the apparel, food processing and plastic industries can expect to be greatly benefited by the principles of CE. However, lack of institutional and structural features exists in the country:

- Low CE literacy among producers/ venders and purchasers
- Improper recycling and industrial symbiosis infrastructure
- Poor measures taken to enact policies
- The shortage of green financing conditions

Nevertheless, all these challenges offer an opportunity to CE implementation in Sri Lanka that corresponds to the UN SDGs and has just the frameworks such as the National Industrial Policy or the attraction of international development agencies. Sri Lanka can create a momentum of circular manufacturing systems by utilizing pilot projects, knowledge-sharing frameworks and promoting and promoting interventions through public-private partnerships.

4.6. Strategic policy-technology alignment and CE maturity

While policy recommendations and enabling conditions for Circular Economy (CE) have been broadly identified, translating these into actionable strategies for implementation especially within SME-dominated economies like Sri Lanka requires structured tools that bridge policy intent with operational practice.

4.6.1. Circular economy maturity matrix (CEMM)

To demonstrate operational relevance, published SME applications of maturity models report measurable improvements when firms progress from Developing to Established maturity (e.g., 12-18% reductions in virgin material demand, 8-14% reductions in waste-handling costs, and improved continuity during input-price volatility). These quantified outcomes support the CEMM's value as a diagnostic and decision-support tool for SME managers and policy agencies.

A CE Maturity Matrix (Saari et al., 2024) provides a staged approach to assess and guide organizations through progressive levels of CE adoption. The matrix can include levels such as:

- Initial: Awareness stage, with ad hoc recycling and minimal CE knowledge.
- Developing: Basic CE practices introduced (e.g., eco-design, waste sorting).
- Established: Integrated CE strategies (e.g., closed-loop supply chains, KPIs).
- Advanced: Data-driven, innovation-focused CE systems supported by digital tools (e.g., blockchain, IoT).

This structured model can help SMEs benchmark their progress, identify gaps, and align with funding or technical assistance programs.

4.6.2. Policy-technology alignment map

To bridge the disconnect between policy levers and enterprise-level action, a strategic Policy Technology Alignment Map is proposed (Geissdoerfer et al., 2020; European Commission, 2020). This map links specific policy instruments with corresponding CE enablers and practices:

Table 3 presents a Policy-Technology Alignment Map linking key policy instruments with enabling Circular Economy practices and supporting digital technologies. The table demonstrates how regulatory tools such as green financing, extended producer responsibility, and public procurement can be operationalized through targeted technological enablers. This alignment highlights the importance of coordinated policy and technology deployment in accelerating CE adoption, particularly for SMEs with limited internal capabilities.

Table 3: Policy-Technology Alignment Map for Circular Economy Implementation

Policy Instrument	Enabling CE Practice	Technological Enabler
Green Financing	Eco-design, energy efficiency	Digital LCA tools, ERP systems
Extended Producer Responsibility (EPR)	Reverse logistics, recycling	IoT-based material tracking
Public Procurement Guidelines	Circular product standards	Blockchain for traceability
Skills & Training Programs	Workforce CE literacy	E-learning platforms
Innovation Grants	Circular business models	AI-driven process optimization

This alignment map illustrates how specific policy instruments can enable targeted CE practices, supported by digital technologies. The integration of policy, practice, and technological tools is essential to scaling CE adoption, particularly in SME-intensive manufacturing contexts such as Sri Lanka

4.7. Comparison with global CE practices

Recent international initiatives further validate the relevance of the tools proposed in this review. For example, the EU-funded CIRCULAR project (2023–2027) emphasizes SME circularity through modular metrics, digital maturity assessment, pilot-based learning, and policy-industry co-creation. Its focus on simplified indicators and staged capability building aligns closely with the CE Maturity Matrix, lightweight SME indicators, and Policy-Technology Alignment Map advanced here, suggesting practical pathways for adaptation in developing economies.

The comparative analysis reveals a big difference between the developed nations and developing economies with regard to CE applications being loaded towards high-tech and data-driven with developed ones and low-cost and high-impact with developing ones. These include:

- Reuse and recovery activities of materials
- Cluster of localized industrial symbiosis
- CE training and skill formation
- Encouraging policy towards circle purchasing and EPR (Extended Producer Responsibility)

Furthermore, the best practice suggests it is important to adopt CE successfully not to replicate but adapt to context as is evidenced in its successful implementation in similar contexts (e.g., India, Indonesia, Vietnam).

4.8. CE metrics standardization for SMEs

While the literature widely acknowledges the absence of standardized CE metrics (Moraga et al., 2019), few solutions are proposed that suit the realities of resource-constrained SMEs, especially in developing economies. To address this, a lightweight and practical indicator framework is proposed, focusing on simplicity, relevance, and feasibility for SMEs in sectors such as textiles and packaging.

Table 4 proposes a simplified Circular Economy metrics framework designed for application in resource-constrained SMEs. The indicators prioritize ease of measurement and operational relevance while capturing core dimensions of circularity, including material efficiency, product longevity, and reliance on secondary inputs. By simplifying complex CE metrics into actionable indicators, the framework addresses a key gap identified in the literature.

Table 4: Proposed CE Metrics Framework

Metric	Definition	Application
Circularity Index	Ratio of recovered/reused output to total output	Tracks material efficiency in production
Repairability Score	Evaluation of product design features enabling disassembly, reuse	Indicates product longevity and reusability
Circular Input Rate (CIR)	% of input from secondary (recycled/biobased) sources	Reflects reliance on non-virgin materials

These indicators draw from and simplify complex metrics (e.g., Material Circularity Indicator, Resource Efficiency Index) into formats SMEs can integrate into routine reporting (Parchomenko et al., 2019; Saidani et al., 2019). They can support internal benchmarking and external compliance (e.g., for green procurement or eco-labeling).

Table 5: Engineering Application in a Textile SME

Production Unit	Circularity Index	Repairability Score (1–5)	CIR (%)
Cotton Shirt Line	0.65	3.5	45%
Recycled Carry Bag Unit	0.89	4.2	92%

Table 5 illustrates a practical application of the proposed CE metrics within a textile SME. The comparison between production units demonstrates how higher circular input rates and repairability scores are associated with stronger circular performance, reinforcing the feasibility of applying lightweight indicators for internal benchmarking and strategic decision-making in SMEs.

Such indicators can empower SMEs to track circular progress without complex life-cycle tools, supporting both operational improvements and strategic alignment with CE goals.

5. Conclusion and recommendations

5.1. Summary of key insights

The systematic literature review (SLR) has been conducted to discuss the role of circular economy (CE) strategies in promoting sustainable growth and resilience of the manufacturing sector. By reviewing 46 out of the available studies, the review demonstrates the development of CE as a strategic framework because it combines the responsibility in taking care of the environment with economic growth and industrial innovation. Accordingly, undermentioned key insights are presented.

- CE solutions like closed-loop supply chain, eco-design, industrial symbiosis and product-as-a-service are the mainstream ways of facing challenges of material efficiency, emission reduction and products lifecycle sustainability.
- The premises are leveraged by increasingly digitizing processes (e.g., IoT, artificial intelligence, blockchain, etc.) to enable real-time monitoring, optimization, and circular innovation.
- Although the CE is conceptually advanced in the high-income regions, the implementation in low and middle-income economies is still impeded by contextual issues that include low awareness level, lack of infrastructure, and insistence in terms of regulation.
- CE implementation is closely associated with the enhancement of supply chain resilience, cost-saving, and resource security, but such effects vary across most contexts.

Their importance is also reflected in the same review where consistency in performance measurement instruments, sector focus as well as exploring CE in SMEs and developing economies were pointers towards appropriate areas which need to be explored in the future.

5.2. Recommendations for policy and practice

- Design a National Circular Economy Roadmap and have simple, sector-based targets and metrics at international standards.
- Advocate the adoption of inclusive laws that will put a demand on the market to use circular solutions like extended producer responsibility (EPR) laws, green public purchasing or eco-design directives.
- Encourage the use of financial instruments (e.g. green bonds, CE innovation grants) and create partnerships between the public and the private to de-risk CE investments.
- Develop capacity-building initiatives and regulatory framework so that experiments can be attempted and stakeholders can be engaged such that SME-heavy industries can be facilitated.

Figure 12 depicts the actor network required for effective Circular Economy implementation in the Sri Lankan manufacturing sector. The framework highlights the central role of government agencies in policy formulation and incentive design, complemented by industry actors responsible for operational adoption of CE practices. Academic and research institutions contribute through capacity building and knowledge transfer, while financial institutions and development agencies enable investment and risk-sharing mechanisms. The coordinated interaction among these actors is critical for overcoming institutional gaps and scaling CE adoption, particularly within SME-dominated manufacturing systems.

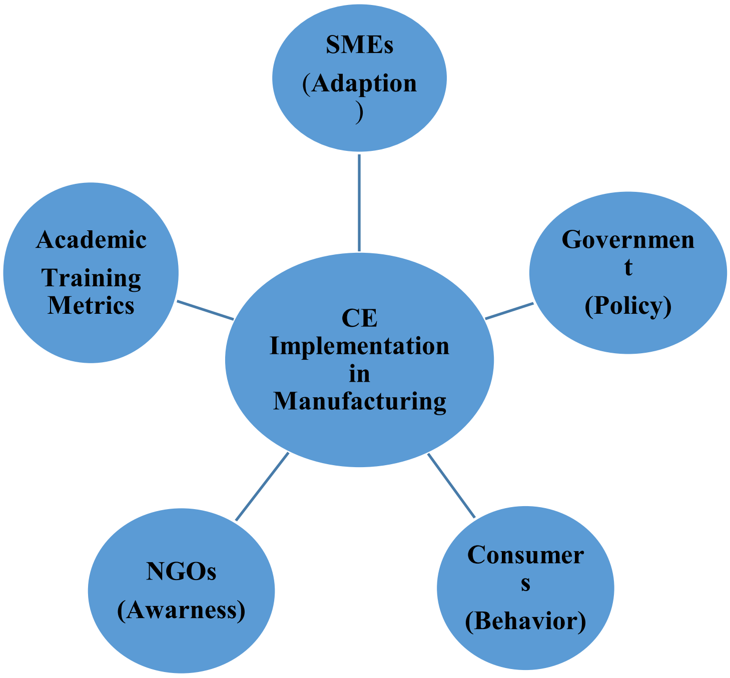

Fig. 12: Actor Network Illustrating Coordinated Stakeholder Roles for Circular Economy Implementation in Sri Lanka's Manufacturing Sector.

5.2.1. Implications for industry players

- Use circular principles when designing by focusing on modularity, repairability, and recyclability.
- Set up material traceability systems with digital tools to enable transparency in lifecycles and tracking in the circle of flow.
- Share resources, infrastructure and learn more about innovations by cooperating in industrial symbiosis platform.
- Organize personnel training and organizational learning to have an internal shift to sustainability.

Table 6 prioritizes selected Circular Economy strategies based on estimated cost, potential impact, and overall implementation priority for the Sri Lankan manufacturing sector. The matrix highlights that low-cost, high-impact interventions such as awareness programs and skills development offer immediate opportunities for accelerating CE adoption, while higher-cost initiatives require targeted policy and financial support. This prioritization supports evidence-based decision-making for policymakers and industry leaders.

Table 6: CE Strategy Prioritization Matrix for Sri Lankan Manufacturing Sector

Action Item	Estimated Cost	Potential Impact	Overall Priority
CE awareness campaigns	Low	High	High
Green finance access for SMEs	High	High	Medium
CE digital platforms	Medium	Medium	Medium
CE curriculum in vocational training	Low	Medium	High
Public-private pilot projects	Medium	High	High
National CE metrics development	Medium	Medium	Medium

5.3. Conclusion

These review results confirm circular economy to be more than a waste management system. It is also a radical avenue to considering differently the way we utilize resources and create value as well as integrating resilience into the manufacturing world. With the mounting global demands on climate change, supply chain disturbance in addition to resource vulnerability beyond the cutoff point, CE provides an excellent system of keepability relative to industrial strength. The need of Sri Lanka and other developing economies is not to mimic the high-tech CE models but rather apply the principles to the local environments with low-cost, high-impact ways and create stakeholder-driven innovation. CE can be integrated into national industrial strategies, cross-sector collaboration mobilized, and human capital invested in so that countries can open the door to an inclusive, regenerative, and future-ready manufacturing economy.

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