

SCALING SUSTAINABILITY: THE ECONOMIC AND ENVIRONMENTAL IMPACT OF CIRCULAR ECONOMY CLUSTERS

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Abstract. This study examines established circular economy clusters in Europe, focusing on their structure, strategies, and impact. The principal objectives are to categorize clusters based on circular models, assess their economic and environmental contributions, and identify key success factors. The investigation covers industrial symbiosis, bio-based production, and policy-led frameworks. The study employs a comparative analysis of key performance indicators (KPIs) and policy frameworks. The findings indicate that collaboration, innovation, and government support are critical factors in driving cluster success while regulatory and market barriers remain challenges. The conclusion emphasizes the need for policy incentives, cross-sector cooperation, and investment in circular innovation to accelerate sustainability.

Keywords: circular economy, cluster, industrial symbiosis, bioeconomy, waste-to-resource, circular models.

JEL Classification: O13, O18, R11.

1. Introduction

The perception of how a cluster is defined has evolved significantly over time. Initially, clusters were understood primarily as groups of companies operating in close geographic proximity, typically within the same economic sector. However, globalization and the increasing complexity of cooperation among companies and other stakeholders have transformed this understanding. Today, clusters are recognized as dynamic networks that encompass a diverse range of actors, including large corporations, small and micro-enterprises, non-profit organizations, universities, research institutions, public administration bodies, civil society organizations, and even individual members (Išoraitė et al., 2024; Mohamed et al., 2024).

Despite the changing definitions, the fundamental purpose and value proposition of clusters remain consistent: to enable knowledge transfer – often referred to in contemporary literature as “technology transfer” – and to facilitate innovation spillovers among

network participants (Radavičius & Tvaronavičienė, 2022). Modern clusters increasingly transcend the boundaries of individual industries, encouraging intersectoral cooperation and the exchange of knowledge to achieve more synergetic and productive outcomes (Ead et al., 2023; Holubčík et al., 2023).

The range of actors participating in these networks is not static and may expand or contract based on specific network objectives. These innovation networks may also be formal or informal in nature, depending on the governance structure and strategic intent (Todorov et al., 2024). The availability of such networks is widely regarded as a favourable element of the broader innovation ecosystem, particularly in fostering the successful development of start-ups (Menshikov et al., 2024). Moreover, clusters, functioning as engines of technology transfer, possess significant potential to enable the diffusion of green innovations, which can accelerate the transition of economies toward a more circular and sustainable state (Meyer, 2024; Mura et al., 2024).

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In the context of growing global uncertainty, rising insecurity, and increased vulnerability of supply chains, clusters and networks are seen as instrumental in enhancing the resilience of economic systems (Grondys & Kot, 2023). Beyond their economic significance, networks also serve as vital communication platforms that can support the achievement of sustainability goals and foster creativity and innovation, even in times of geopolitical turmoil or war (Išoraitė & Alperytė, 2023; Samašonok & Išoraitė, 2023).

The significance of clusters in facilitating sustainable development and economic resilience has been further underscored in previous research. Tvaronavičienė et al. (2024) demonstrated that circular economy (CE) practices implemented at macro, mezzo, and micro levels can contribute to societal resilience by fostering efficient resource use, reducing dependency on non-renewable energy sources, and promoting sustainable economic growth. Their findings emphasize the pivotal role of CE initiatives and networks in strengthening resilience to energy shocks and advancing long-term sustainability objectives.

Although the advantages of clusters and networks have been acknowledged and widely researched over the past two decades, their practical implementation remains complex and challenging. This complexity is particularly evident in the context of the circular economy, where diverse stakeholder engagement, cross-sector collaboration, and systemic transformation are essential.

This study aims to examine established circular economy clusters in Europe, focusing on their structure, strategies, and impact. Specifically, the objectives are to categorize clusters based on circular models, assess their economic and environmental contributions, and identify key success factors. The investigation covers industrial symbiosis, bio-based production, and policy-led frameworks through a comparative analysis of key performance indicators (KPIs) and policy frameworks.

By exploring these clusters, the study seeks to contribute to the broader discourse on how circular economy practices can be scaled and institutionalized at regional and national levels, ultimately supporting sustainability and resilience goals.

2. Methodology

This methodological approach is aligned with the study's objective of providing a comparative, evidence-based assessment of circular economy (CE) clusters in Europe. The study employs a qualitative, multi-case study approach combined with secondary data analysis to investigate the structure, strategies, and performance of CE clusters. The research design is structured into three sequential phases: literature review and framework development, case selection, and data analysis.

2.1. Literature selection and framework development

The framework development process began with a Systematic Literature Review (SLR) to establish a structured basis for analysing circular economy clusters. The Scopus database was selected as the primary source due to its comprehensive coverage of peer-reviewed academic literature (Elsevier, n.d.). A targeted search query was formulated to identify relevant publications using the following keywords: ("Circular Economy Clusters" OR "Industrial Symbiosis") AND ("Economic impact" OR "Environmental impact") AND ("Europe"). This search resulted in 1,555 documents.

A set of exclusion and inclusion criteria was then applied to refine the selection:

- Timeframe: Limited to publications before 2020 to capture recent research trends (reduced to 1,136 documents).
- Language: Restricted to English-language publications to ensure consistency and accessibility (1,122 documents).
- Document Type: Limited to articles and conference papers, excluding reviews, book chapters, books, short surveys, notes, and editorials (739 documents).
- Access: Open access publications were prioritized to enable unrestricted review (453 documents).
- Relevance: Titles and abstracts were screened to exclude studies unrelated to circular economy clusters, resulting in a final subset of 134 documents.

A detailed content review of these documents was then conducted, leading to the selection of 60 publications based on their relevance to the research objectives. These selected papers formed the foundation for developing a comprehensive analytical framework, categorizing circular economy clusters by geography, sectoral focus, and circular economy model (e.g., industrial symbiosis, bio-based production, and policy-led frameworks).

2.2. Case selection

A purposive sampling strategy was employed to select four representative circular economy clusters across different European regions. The selection criteria were designed to ensure diversity in terms of geographic location, sectoral focus, and circular economy models applied.

Specifically, clusters were chosen to reflect geographical diversity by including examples from Northern, Western, Southern, and Eastern Europe. The selection also aimed to capture a variety of circular economy models, such as industrial symbiosis, bio-based production, and policy-led frameworks. An additional criterion was the availability of publicly accessible data on each cluster's structure, economic and environmental performance, and governance frameworks. Based on these criteria, four clusters were selected: Kalundborg Symbiosis (Denmark), Industrial Symbiosis Network (United Kingdom),

Lombardy Green Chemistry Cluster (Italy), and Romanian Circular Economy Initiative (Romania).

2.3. Data collection

The study relied solely on secondary data sources, drawing from academic publications, such as reviewed articles and conference papers related to CE clusters. It also utilised policy documents and reports, including EU Circular Economy Action Plan, national strategies, and regional policy frameworks. Industry reports and databases, such as those from the European Cluster Collaboration Platform, the Ellen MacArthur Foundation, and cluster-specific annual reports, were also consulted. In addition, cluster-specific documentation – including strategic plans, sustainability reports, and official websites of the selected clusters – provided valuable insights.

Additionally, the study gathered data on key economic and environmental indicators such as cost savings, job creation, CO₂ emissions reduction, and improvements in resource efficiency.

2.4. Data analysis

The study applied a combination of content analysis and comparative case study analysis. Qualitative content analysis was conducted on policy documents, academic publications, and cluster reports to identify core strategies, governance mechanisms, and circular economy models used by each cluster. In parallel, a comparative analysis was carried out to assess the four clusters, focusing on their circular economy implementation models, economic and environmental performance, and governance structures. Additionally, secondary data on economic and environmental impacts were analysed using descriptive statistics to highlight differences and similarities across clusters. Indicators included cost savings, investment levels, employment generation, resource circularity rates, and CO₂ emission reductions.

2.5. Identification of success factors and challenges

The analysis further synthesized common patterns, enabling conditions, and barriers across the selected clusters. Success factors and challenges were identified based on recurring themes observed in the literature, policy documents, and cluster performance data.

This methodological approach enabled a systematic and evidence-based comparative review of how different European clusters implement circular economy principles and achieve economic and environmental outcomes.

3. Literature review

The transition from linear to circular economic models has become an imperative response to pressing global challenges such as resource depletion, environmental degradation, and socio-economic inequalities. Within this broader paradigm shift, circular economy (CE)

clusters have emerged as a particularly promising model for accelerating sustainable economic development. These clusters, defined as networks of interconnected stakeholders – including firms, policymakers, and research institutions – operate collaboratively to implement circular strategies at various systemic levels. Over the last decade, an expanding body of academic literature has explored the structure, strategies, and performance of such CE clusters, providing valuable insights into their practical application, economic and environmental impact, and the barriers and enablers of their success.

A comprehensive review of 60 recent publications reveals the diversity of CE models adopted by clusters across Europe. These models vary in their scope, strategic orientation, and sectoral applicability but share a common objective: to minimize waste, maximize resource efficiency, and promote economic resilience. Among the most widely discussed models in the literature is *Industrial Symbiosis (IS)*. IS focuses on facilitating resource sharing among industrial actors within a defined geographical area, allowing companies to exchange materials, energy, water, and by products to reduce environmental impact and operational costs. Numerous studies emphasize the foundational role of IS in CE clusters, highlighting its potential to foster emissions reduction, waste valorisation, and regional sustainability gains (Azevedo et al., 2021; Chrysiopoulos et al., 2024; Gamidullaeva et al., 2024; Oughton et al., 2022).

Complementary to IS, the *Fields of Action Model* offers a value-chain perspective by identifying six sequential stages – Take, Make, Distribute, Use, Recover, and Industrial Symbiosis – that encourage circular practices throughout a product's lifecycle. This model has been widely adopted in sectors such as manufacturing and logistics, providing a practical framework for integrating circularity into operational processes (Leal et al., 2025). Another influential model is the *ReSOLVE Framework*, which provides strategic guidance for organizations seeking to transform their business models. Comprising six action levers – Regenerate, Share, Optimize, Loop, Virtualize, and Exchange – the framework promotes both technological innovation and behavioural change to achieve systemic circularity (Alka et al., 2024; Raman et al., 2024).

At the product and business model level, *Product-Service Systems (PSS)* and *Circular Business Models (CBMs)* are frequently discussed in the literature. These models aim to extend product life cycles and shift consumer behaviour away from ownership towards service-based consumption. Empirical studies report that these models are particularly prevalent in sectors such as electronics, textiles, and packaging, where leasing, repair, and reuse strategies can generate significant sustainability benefits (Baldassarre & Calabretta, 2024; Ekdahl et al., 2024; Mayanti & Helo, 2024). To prioritize circular strategies and assess their effectiveness, many clusters apply the *9R/10R Frameworks*, which propose a hierarchy of circular interventions ranging from Refuse and Rethink at the top to

Recycle and Recover at the bottom (Muñoz et al., 2024; Sardinou et al., 2024; Wiebe et al., 2023).

Another cluster of models centres around regenerative design principles, notably the *Cradle-to-Cradle* and *Bio-based Models*. These frameworks advocate for the creation of products and services that are safe for biological cycles and compatible with industrial reuse, aligning economic activities with ecosystem sustainability. Studies highlight their successful application in sectors such as packaging, food, and construction materials (Bezama et al., 2022; Bonoli et al., 2020; Uwuigbe et al., 2025). Collectively, these models illustrate the strategic and operational diversity of CE clusters, providing multiple pathways to foster sustainable production and consumption systems.

Beyond structural models, the literature offers robust evidence on the *economic impacts* of CE clusters. Numerous studies affirm that CE clusters can generate direct and indirect economic benefits, ranging from cost reductions to regional economic development. For instance, Uwuigbe et al. (2025) report that improved resource productivity and waste reduction in CE clusters can lead to cost savings of up to 20% for participating firms. Similarly, Banelienė and Strazdas (2023) found a statistically significant positive relationship between green innovation and GDP growth across European Union countries, with some sectors demonstrating up to a 3.5% GDP increase attributable to CE-related innovations. The implementation of IS initiatives has also been linked to reduced production costs and job creation; Hossain et al. (2024) noted that such initiatives can lower production costs by up to 15% while boosting local employment opportunities.

Additional research underscores the role of policy and strategic alignment in enhancing the economic performance of CE clusters. Leal et al. (2025) report that manufacturing firms in Germany implementing CE practices achieved up to 30% higher returns on eco-innovation investments compared to traditional operations. Hartley et al. (2023) emphasize the importance of targeted public investments and policy frameworks in unlocking the economic potential of CE clusters, while Baldassarre and Calabretta (2024) highlight the profitability of CBMs when aligned with market demand. Furthermore, Maranesi and De Giovanni (2020) and Wilke and Pyka (2025) argue that CE clusters improve firm competitiveness by fostering localized supply chains, resource synergies, and knowledge sharing.

To systematically assess these economic impacts, researchers have developed various *key performance indicators (KPIs)*. These include cost savings from resource efficiency and shared infrastructure, revenue growth from circular products and services, employment generation in green sectors, return on investment (ROI) in CE initiatives, and increased market share resulting from innovation. Additionally, the degree of policy incentive utilization – such as subsidies and tax benefits – has been identified as a relevant indicator of public sector support

for CE clusters (Henriques et al., 2021; Pacurariu et al., 2021).

Alongside their economic contributions, CE clusters deliver significant *environmental benefits* by reducing emissions, minimizing waste, and enhancing resource efficiency. Several empirical studies document these outcomes. For example, Karkou et al. (2024) found that closed-loop water and energy systems within CE clusters can reduce water usage by up to 40%. Raman et al. (2024) reported that energy efficiency upgrades implemented in CE clusters can cut carbon emissions by 25–30% within five years. In the packaging sector, Ada et al. (2023) demonstrated that circular solutions reduced waste generation by more than 60%, while Harfeldt-Berg (2024) observed a 35% reduction in landfill dependency through waste valorisation strategies.

Further evidence supports the environmental gains associated with industrial symbiosis and resource valorisation practices. Bonoli et al. (2020) showed that the use of industrial by-products such as reclaimed asphalt pavement (RAP) and steel slag in asphalt manufacturing significantly reduces greenhouse gas emissions. Chinese et al. (2022) highlighted the positive environmental impact of symbiotic energy systems in the agri-food sector, reporting lower carbon intensity and higher renewable energy uptake. Likewise, Paulu et al. (2022) and Lakanen et al. (2022) provided evidence that CE clusters support circular nutrient cycles and reduce ecological damage through waste valorisation and nitrogen handprint tracking.

Several environmental KPIs are commonly adopted in assessing CE cluster performance. These include greenhouse gas (GHG) emissions reduction, waste diversion rates, resource efficiency metrics such as water and energy use, the Material Circularity Indicator (MCI), and biodiversity protection measures (Grimmel et al., 2024; Muñoz et al., 2024; Ravikumar et al., 2024). Importantly, these environmental gains contribute to broader policy objectives such as the United Nations Sustainable Development Goals (SDGs), particularly those related to responsible consumption and production, climate action, and clean water and sanitation (Raman et al., 2024; Sardinou et al., 2024).

Despite their demonstrated benefits, CE clusters face numerous *challenges* in practice. A recurring theme in the literature is the lack of cohesive and supportive policy frameworks. In many regions, regulations remain fragmented or outdated, providing insufficient incentives or guidance for circular initiatives (Henriques et al., 2021; Hossain et al., 2024; Sardinou et al., 2024). Technological limitations also hinder CE implementation, particularly for small and medium-sized enterprises (SMEs) that lack access to advanced tools, clean technologies, and infrastructure upgrades (Baldassarre & Calabretta, 2024; Nessim et al., 2023).

Organizational and cultural barriers further complicate CE cluster development. Many firms maintain a short-term focus on profitability and exhibit resistance

to the organizational change required for CE adoption (Azevedo et al., 2021; Brändström et al., 2024). The literature also highlights the complexity of monitoring and measuring circularity performance. The absence of standardized indicators and assessment tools can impede decision-making and hinder policy and financial support (Grimmel et al., 2024; Muñoz et al., 2024; Pacurariu et al., 2021). Additionally, limited cross-sector communication, underdeveloped supply chain linkages, and insufficient stakeholder coordination present structural challenges to effective CE implementation (Borbon-Galvez et al., 2021; Oughton et al., 2022).

To overcome these barriers, scholars have identified several *critical success factors* (CSFs) that facilitate the effective implementation and long-term sustainability of CE clusters. First and foremost, strong policy support is essential. Governments can accelerate CE transitions through green public procurement, regulatory mandates, financial incentives, and the alignment of policies across sectors and administrative levels (Ekdahl et al., 2024; Hartley et al., 2023; He & Li, 2023; Raman et al., 2024). Collaboration among diverse stakeholders is another cornerstone of success. Multi-stakeholder partnerships involving public authorities, private firms, academia, and civil society enhance trust, promote shared visions, and improve logistical coordination (Gamidullaeva et al., 2024; Gourgiotis et al., 2021; Wilke & Pyka, 2025).

Technological readiness also plays a central role. The use of digital platforms, IoT, blockchain, and clean technologies enables more efficient resource tracking, transparency, and material exchange (Grimmel et al., 2024; Silva et al., 2022). Furthermore, education and awareness-building initiatives are indispensable for driving cultural change and stakeholder engagement. Training programs, workshops, and knowledge dissemination activities are critical enablers of CE cluster development (Raman et al., 2024; Sardianou et al., 2024; Uwuigbe et al., 2025).

Finally, access to financial and institutional resources is crucial, particularly for SMEs and regional initiatives. Long-term governance continuity, strategic planning, and decision-support tools further enhance the adaptability and performance of CE clusters (Azevedo et al., 2021; Baldassarre & Calabretta, 2024; Hartley et al., 2023; Henriques et al., 2021; Muñoz et al., 2024; Nessim et al., 2023; Ravikumar et al., 2024).

In summary, the literature highlights that CE clusters hold significant potential to deliver economic, environmental, and social benefits when supported by strategic governance, stakeholder collaboration, technological readiness, and coherent policy frameworks. These insights form the conceptual foundation of this study's analysis of selected European CE clusters.

4. Case study analysis

The authors systematically selected and analysed four key circular economy (CE) clusters in Europe to provide

a representative and balanced view of circular economy implementation across different models, sectors, and geographic regions. The selection was guided by two main criteria: (1) ensuring diversity in the circular models represented, and (2) covering distinct geographic regions within Europe to avoid regional bias. This approach ensured that the analysis captured both the strategic diversity and geographical spread of CE initiatives in Europe.

The final four clusters reflect a broad spectrum of circular economy models and geographic diversity (Table 1):

Table 1. Selected European Circular Economy Clusters

Cluster Name	Country	Relevant Circular Models
Kalundborg Symbiosis	Denmark	Industrial Symbiosis (IS)
Industrial Symbiosis Network (UK)	UK	Industrial Symbiosis (IS), 9R/10R Frameworks
Lombardy Green Chemistry Cluster	Italy	Cradle-to-Cradle / Bio-based
Romanian Circular Economy Initiative	Romania	Fields of Action Model, ReSOLVE Framework

This selection includes clusters from Northern (Denmark), Western (UK), Southern (Italy), and Eastern (Romania) Europe, ensuring a balanced geographic scope.

The selected clusters illustrate the practical application of different circular economy models identified in the systematic literature review. Kalundborg Symbiosis and the Industrial Symbiosis Network (UK) embody the Industrial Symbiosis (IS) model, focusing on system-wide resource sharing and waste valorisation (Kalundborg Symbiosis, n.d.; Ellen MacArthur Foundation, n.d.; Innovate UK Business Connect, 2025; WRAP, n.d.); The UK network also incorporates elements of the 9R/10R Frameworks, emphasizing operational circular strategies such as recycling and resource recovery. The Lombardy Green Chemistry Cluster represents the Cradle-to-Cradle / Bio-based model, promoting regenerative production and bioeconomy integration (European Commission, n.d.; Lombardy Green Chemistry Association, n.d.). Lastly, the Romanian Circular Economy Initiative reflects a policy-led approach grounded in the Fields of Action Model and the ReSOLVE Framework, aiming to coordinate national efforts and stakeholder engagement for circularity (ECCP, n.d.-a; n.d.-b).

4.1. Economic performance

The selected clusters demonstrate positive economic outcomes associated with circular economy strategies. Kalundborg Symbiosis (n.d.) reports €28 million in annual cost savings and supports industrial expansion through its cross-sector symbiosis model. Similarly, the Industrial Symbiosis Network (UK) (IEMA, n.d.) generates cost reductions across multiple industries by facilitating the reuse of industrial waste.

In Southern Europe, the Lombardy Green Chemistry Cluster (LGCA, n.d.) shows economic benefits through investment in bio-based industries and the promotion of a regional bioeconomy ecosystem. The Romanian Circular Economy Initiative (ECCP, n.d.-b) reflects a national approach, with KPIs highlighting the development of a national strategy and the potential for economic uplift by positioning Romania as a CE leader in Eastern Europe.

These economic KPIs illustrate that CE clusters can achieve cost savings, regional investment, and national economic positioning when supported by collaborative frameworks and clear circular strategies.

4.2. Environmental impact

Environmental KPIs across the clusters highlight significant contributions to sustainability goals. Kalundborg Symbiosis (n.d.) achieves a 635,000-ton reduction in CO₂ emissions and 97% material circularity, demonstrating the effectiveness of system-level resource sharing. The UK network (Innovate UK Business Connect, 2025) reports measurable reductions in landfill waste and improvements in energy efficiency through closed-loop processes.

The Lombardy cluster (LGCA, n.d.) contributes to environmental sustainability by developing sustainable chemicals and bio-based products, aligning with regenerative circular models. Romania's initiative (ECCP, n.d.-b) emphasizes improved material reuse potential and waste reduction targets as part of its national CE strategy.

These outcomes underline the capacity of CE clusters to deliver tangible environmental benefits through the implementation of targeted circular practices and policies.

4.3. Resource efficiency and circular business practices

Resource efficiency is a defining feature of all selected clusters. Kalundborg's model is built on heat, water, and material exchange across industrial partners, resulting in optimized resource use (Kalundborg Symbiosis, n.d.). The UK network facilitates the repurposing of industrial waste for use in other sectors (WRAP, n.d.). In Italy, the Lombardy cluster promotes the efficient use of biomass and organic waste to support bio-based production systems (LGCA, n.d.). Romania's national strategy emphasizes the enhancement of industrial recycling and waste-to-resource pathways, reflecting a policy-driven commitment to resource efficiency (ECCP, n.d.-b).

Circular business practices are embedded in each cluster. Kalundborg and the UK network exemplify industrial symbiosis and closed-loop production systems, while Lombardy promotes green chemistry and bio-based solutions. Romania's initiative adopts a participatory approach by facilitating stakeholder-driven identification of circular opportunities.

4.4. Success factors

The cross-case analysis of these clusters highlights several key success factors. First, the clusters demonstrate strong *strategic alignment* between CE models and regional strengths, industrial profiles, and policy environments. Second, *stakeholder collaboration* emerges as a critical element, with strong partnerships between public and private stakeholders playing a central role. Examples include Kalundborg's long-standing collaboration, the UK network's national engagement, Lombardy's public-private partnerships, and Romania's policy-led stakeholder inclusion. Third, effective *policy support and governance* have been pivotal, as seen in Kalundborg and the UK network's access to national and EU-level support, Lombardy's cluster targeted R&D investments, and Romania's integration of CE strategies into government policy. Finally, *innovation and resource optimization* are priorities across all clusters, with efforts directed at enhancing resource efficiency at system, value chain, and product levels, delivering both environmental and economic gains. Overall, these factors confirm that CE clusters thrive when supported by collaborative governance, strategic innovation, and aligned policy instruments.

4.5. Comparative insights and cross-analysis

A comparative analysis of the four clusters reveals both shared characteristics and strategic differences:

- *System-Level vs. Policy-Level Approaches*: Kalundborg and the UK network exemplify bottom-up, industry-driven industrial symbiosis, rooted in practical collaboration and mutual resource use (Kalundborg Symbiosis, n.d.; Innovate UK Business Connect, 2025; WRAP, n.d.). In contrast, Romania's initiative is driven by a top-down, policy-coordinated strategy, aiming to institutionalize circularity at the national level (ECCP, n.d.-b).
- *Sectoral Specialization*: While Kalundborg and the UK network focus on industrial and manufacturing sectors, Lombardy's cluster targets the bioeconomy and green chemistry, illustrating the adaptability of CE models to sector-specific contexts (LGCA, n.d.).
- *Geographic and Institutional Diversity*: The clusters span Northern, Western, Southern, and Eastern Europe, reflecting different industrial landscapes and policy contexts. This diversity enhances the generalizability of the findings and demonstrates that circular economy principles can be effectively operationalized in varied settings.

Despite these contextual differences, all clusters converge on the fundamental principles of resource efficiency, stakeholder collaboration, and policy alignment, confirming the versatility and scalability of circular economy models.

4.6. Implications

The findings of this study underscore the importance of strategic, context-specific approaches to circular economy implementation. Policymakers and practitioners should recognize the value of tailoring CE strategies to regional strengths, fostering multi-stakeholder partnerships, and investing in innovation and governance structures that enable long-term circular transitions. The selected clusters collectively illustrate that circular economy principles can be operationalized at scale while addressing regional priorities and sustainability challenges.

5. Conclusions

This study has examined the structure, strategies, and performance of circular economy (CE) clusters in Europe, focusing on four representative initiatives: Kalundborg Symbiosis (Denmark), Industrial Symbiosis Network (United Kingdom), Lombardy Green Chemistry Cluster (Italy), and the Romanian Circular Economy Initiative (Romania). Through a combination of systematic literature review, secondary data analysis, and comparative case study methodology, the research provides valuable insights into the diverse ways in which CE principles are operationalized across different regional, sectoral, and governance contexts.

The findings of this study confirm that CE clusters represent an effective mechanism for advancing sustainability, regional economic development, and industrial innovation. The selected clusters illustrate the practical application of various circular economy models, including industrial symbiosis, bio-based production systems, and policy-led circular frameworks. Despite their contextual differences, all clusters demonstrate a commitment to resource efficiency, stakeholder collaboration, and systemic integration of circular principles.

The analysis reveals that CE clusters generate significant economic and environmental benefits. Economic impacts include cost savings through resource sharing, increased investment in green industries, and the creation of employment opportunities in emerging circular sectors. Environmental gains are equally notable, encompassing substantial reductions in greenhouse gas emissions, waste diversion from landfills, and improvements in overall resource efficiency. These outcomes align with broader policy objectives such as the European Green Deal and the United Nations Sustainable Development Goals (SDGs).

The comparative analysis further identifies several critical success factors that underpin the effectiveness of CE clusters. These include strategic alignment between circular models and regional industrial profiles, strong policy support and public investment, active stakeholder collaboration, and a clear focus on technological and organizational innovation. However, the study also highlights persistent challenges to CE implementation, including fragmented policy frameworks, technological limitations, insufficient financial

resources for SMEs, and the lack of standardized performance indicators.

By synthesizing these insights, the study contributes to the growing body of knowledge on circular economy implementation. It emphasizes the importance of adopting a systemic, context-specific, and multi-stakeholder approach to foster the long-term viability of CE clusters. Policymakers and practitioners should prioritize enabling environments that support CE transitions, including coherent regulatory frameworks, targeted financial incentives, and platforms for cross-sectoral collaboration.

Future research could build on this study by conducting longitudinal analyses of CE cluster development and exploring the socio-economic impacts of circular initiatives in greater depth. Additionally, further investigation into monitoring frameworks and standardization of circular performance metrics would enhance the ability of stakeholders to evaluate progress and scale successful models.

In conclusion, the experience of European CE clusters demonstrates that circular economy strategies, when effectively implemented and supported, can deliver tangible economic, environmental, and social benefits. Scaling and replicating these initiatives across regions will be crucial to advancing the circular transition and achieving long-term sustainability objectives.

Disclosure statement

Authors declare that they do not have any competing financial, professional, or personal interests from other parties.

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