


Circular Economy and Regional Innovation Systems



Economía circular como estrategia para el desarrollo territorial y ecosistemas de innovación.

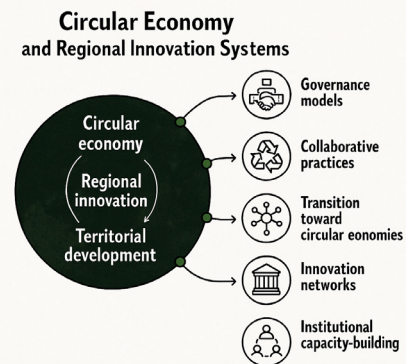
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HIGHLIGHTS

- This article examines the integration of circular economy principles into regional innovation systems to promote sustainable territorial development.
- It identifies governance models and collaborative practices that drive the transition toward circular economies at the regional level.
- Latin American case studies demonstrate the potential of innovation networks and institutional capacity-building to advance circular strategies.

GRAPHICAL ABSTRACT



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Keywords:

Circular economy, Regional innovation systems, Territorial development, Governance, sustainability

Palabras clave:

Economía circular, Sistemas regionales de innovación, Desarrollo territorial, Gobernanza, sostenibilidad.

This article analyzes how circular economy (CE) can be integrated into regional innovation systems (RIS) as a strategy for sustainable territorial development. A comparative study was conducted across three Latin American regions—Antioquia (Colombia), Jalisco (Mexico), and Lima (Peru)—using a qualitative approach based on Structural Strategic Mapping (SSM), semi-structured interviews, and document analysis. Results indicate that EC–RIS integration depends on institutional configuration, multi-actor cooperation, and the quality of the regional innovation ecosystem. Strategic variables behave as linking factors, highly influential and dependent, requiring coordinated and systemic interventions. Key enabling factors include governance, talent development, financing, and business participation, while common challenges include institutional fragmentation and a lack of circularity indicators. The study concludes that successful integration calls for a balanced capacity architecture, a shared vision of development, and adaptive strategies tailored to local contexts.

RESUMEN

Este artículo analiza cómo puede integrarse la economía circular en los sistemas regionales de innovación como estrategia para el desarrollo territorial sostenible. A partir del estudio comparado de tres regiones latinoamericanas —Antioquia (Colombia), Jalisco (México) y Lima (Perú)— se aplicó un enfoque cualitativo basado en el Mapeo Estructural Estratégico (MSE), entrevistas semiestructuradas y análisis documental. Los resultados revelan que la integración EC–SRI depende de la configuración institucional, la cooperación multiactor y la calidad del ecosistema regional. Las variables estratégicas clave se comportan como factores de enlace, altamente influyentes y dependientes, lo que exige intervenciones integradas. Se identifican factores críticos como la gobernanza, la formación de talento, el financiamiento y la participación empresarial, así como retos comunes asociados a la fragmentación institucional y la falta de indicadores circulares. El estudio concluye que el éxito de esta articulación requiere una arquitectura de capacidades equilibrada, visión compartida del desarrollo y estrategias adaptativas basadas en las condiciones locales.

1. Introduction

Over the past decades, the need to redesign economic development models has acquired unprecedented urgency, driven by the climate crisis, environmental degradation, and persistent territorial inequality. In this context, the circular economy (CE) has emerged as a regenerative alternative to the linear model of production and consumption, proposing a logic of closed loops, efficient resource use, and restoration of natural systems. In parallel, regional innovation systems (RIS) have been recognized as institutional, productive, and academic environments that interact to generate territorial value through knowledge, technology, and collaboration.

The convergence of these two approaches—circularity as a strategy and innovation as a system—offers a promising framework for the design of public policies aimed at sustainable territorial development. However, this integration remains incipient, particularly in Latin American contexts where structural challenges such as institutional fragmentation, limited resources, and weak articulation among innovation ecosystem actors persist. Nevertheless, significant progress has been observed in territories that have begun to transition toward circular and collaborative production models.

This article aims to analyze how the circular economy can be integrated into regional innovation systems as a strategy for sustainable territorial development, through a study of three Latin American regions: Antioquia (Colombia), Jalisco (Mexico), and the Metropolitan Region of Lima (Peru). These regions were selected due to their progress in circular initiatives, presence of active universities, sustainability policies, and emerging innovation dynamics.

To this end, the study employed a qualitative-comprehensive methodology based on Structural Strategic Mapping (SSM), complemented by semi-structured interviews, document analysis, and institutional field observation. This approach allowed the identification of eight strategic variables that influence CE–RIS integration, including regional technological capacity, governance, public-private cooperation, and financing for circular innovation. The comparative analysis revealed that Jalisco presents the most robust ecosystem, particularly in public policy and business participation; Antioquia stands out for its multi-actor governance and cooperation networks; and Lima excels in the role of universities, although it faces limitations in state structure and funding mechanisms.

The findings show that the strategic variables function as linking factors, meaning they are both highly influential and highly dependent, which necessitates the adoption of systemic and coordinated approaches. Additionally, semantic analysis of interviews highlighted recurring concepts such as “open innovation,” “industrial symbiosis,” “triple helix,” and “environmental education,” evidencing an emerging symbolic capital that supports the circular transition, albeit with significant challenges in terms of institutionalization, impact measurement, and cultural transformation.

This research contributes to the field of sustainability and territorial innovation by offering a contextualized and structured analysis of the factors that enable—or constrain—the circular transition in different territories. Ultimately, it proposes a working agenda based on collaborative strategies, talent development, institutional strengthening, and adaptive governance as key pillars to consolidate sustainable regional innovation ecosystems in Latin America.

2. Theoretical Framework

2.1. Circular Economy: Conceptual Foundations and Theoretical Evolution

The circular economy (CE) has evolved as a paradigm that seeks to redefine growth, focusing on generating positive outcomes for society as a whole. [Geissdoerfer et al. \(2017\)](#) emphasize that CE is built upon three pillars: the preservation and enhancement of natural capital, the efficient use of available resources, and the improvement of system performance. This approach contrasts with the traditional linear model of “take, make, dispose,” proposing instead a regenerative system by design.

[Korhonen et al. \(2018\)](#) argue that although CE has gained popularity, its implementation faces challenges due to the lack of a unified definition and the need for clear indicators to measure progress. In this regard, [Kirchherr et al. \(2017\)](#) conducted a systematic review revealing the diversity of interpretations surrounding CE, which can hinder its practical application. Nevertheless, [Bocken et al. \(2016\)](#) propose archetypes of circular business models that can serve as practical guides for companies transitioning toward more sustainable practices.

In summary, the literature suggests that although CE offers a promising framework for sustainability, its effective implementation requires a clear understanding of its principles and the adaptation of business models that incorporate those concepts.

Table 1. Main Theoretical Approaches to the Circular Economy

Author(s)	Year	Main Approach	Key Contribution
Geissdoerfer et al.	2017	Fundamental principles of CE	Defined three core pillars of the circular economy paradigm
Korhonen et al.	2018	Implementation challenges	Identified barriers and the need for standardized progress indicators
Kirchherr et al.	2017	Systematic review of CE definitions	Revealed the diversity of CE interpretations and its implications for application

Bocken et al.	2016	Circular business model archetypes	Proposed practical archetypes to guide business transitions toward sustainability
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Source: Compiled by the authors based on the reviewed literature.

The most relevant theoretical contributions in the field of circular economy are highlighted, emphasizing each author’s key perspectives and contributions. These works provide a solid foundation for understanding both the principles and the challenges associated with implementing CE.

The literature review indicates that, in order to effectively integrate the circular economy into regional innovation systems, it is essential to have a deep understanding of its theoretical foundations and to adapt business models that reflect these concepts. Such integration can serve as a key strategy for sustainable territorial development.

2.2. Regional Innovation Systems: Structures and Dynamics

Regional Innovation Systems (RIS) refer to the network of institutions within a region that interact to generate and apply innovative knowledge. [Cooke et al. \(1997\)](#) introduced the concept, emphasizing the importance of interactions among businesses, research institutions, and local governments. [Sheim & Gertler. \(2005\)](#) expanded on this idea, highlighting regional differences in learning capacities and institutional structures.

[Lundvall. \(1992\)](#) proposed the national innovation systems approach, which has been adapted to the regional context by authors such as [Doloreux & Parto. \(2005\)](#). These scholars argue that the defining characteristics of a region—such as its culture and economic structure—shape the way innovation processes unfold. Additionally, [Tödting & Trippl. \(2005\)](#) identified different types of RIS, such as metropolitan, peripheral, and old industrial regions, each with unique challenges and opportunities.

The literature also underscores the importance of governance in RIS. [Rodríguez-Pose. \(2013\)](#) points out that the quality of regional institutions can significantly affect a region’s ability to innovate and adapt to economic and technological change.

Table 2. Key Characteristics of Regional Innovation Systems

Autor(es)	Año	Enfoque principal	Contribución clave
Cooke et al.	1997	Introducción del concepto de SRI	Definición y componentes clave de los SRI
Sheim & Gertler	2005	Capacidades de aprendizaje regional	Diferencias regionales en estructuras institucionales y capacidades de aprendizaje
Doloreux & Parto	2005	Adaptación del enfoque nacional al regional	Influencia de características regionales en procesos de innovación
Tödting & Trippl	2005	Tipología de SRI	Identificación de diferentes tipos de SRI y sus desafíos específicos

Source: Compiled by the authors based on the reviewed literature.

The most relevant contributions to the study of regional innovation models are presented, highlighting how different authors have conceptualized and analyzed the structures and dynamics that characterize them.

Understanding the design and dynamics of regional innovation systems is essential for integrating the circular economy into territorial development. The interaction between institutions, businesses, and local governments can facilitate the adoption of circular practices tailored to the specific characteristics of each region.

2.3. Integrating the Circular Economy into Regional Innovation Systems

Circular economy (CE) and regional innovation systems (RIS) have traditionally been analyzed separately. However, recent literature proposes their convergence as a key strategy for sustainable territorial development. According to [D’Amato et al. \(2020\)](#), this integration requires transforming local production processes, redesigning business models, and fostering synergies among territorial ecosystem actors. Likewise, [Domenech & Bahn-Walkowiak. \(2019\)](#)

emphasize the need for specific public policies that connect regional innovation capacities with CE principles to enable the transition toward more resilient and regenerative production models.

In regions where innovation ecosystems are still emerging, such as many in Latin America, integrating CE into RIS requires overcoming institutional and cultural barriers. [Cayzer et al. \(2017\)](#) argue that one of the greatest challenges in this convergence is the lack of articulation between technical knowledge and the institutional capacity of local governments. Similarly, [Callegari et al. \(2023\)](#) underscore the importance of alliances among universities, R&D centers, industrial clusters, and local governments as key vehicles to implement circular innovation—especially in sectors with a high environmental footprint.

[Pauliuk. \(2018\)](#), on the other hand, suggests that effective integration requires a systemic approach that combines technological innovation with cultural and behavioral change. This involves adaptive governance frameworks, the use of clean technologies, and specific funding mechanisms for circular projects. In this way, RIS can evolve into sustainable innovation systems, capable of regenerating the socioeconomic and ecological fabric of their respective territories.

Table 3. Key Authors on CE–RIS Integration

Author(s)	Year	Main Focus	Key Contribution
D’Amato et al.	2020	Territorial strategies for CE	Proposed pathways for embedding CE into local production processes
Domenech, T., & Bahn-Walkowiak	2019	Public policy and institutional coordination	Emphasized the need for policies that connect CE with regional innovation capacities
Cayzer et al.	2017	Organizational synergies for CE in RIS	Identified the gap between technical knowledge and institutional capacity
Callegari et al.	2023	Collaborative networks for circular innovation	Highlighted alliances among universities, R&D centers, and local governments

Source: Compiled by the authors based on the reviewed literature.

The main theoretical and empirical contributions that address the articulation between circular economy and regional innovation systems are summarized. These authors highlight both the enabling factors and the existing barriers to achieving effective convergence. The literature agrees on the need for systemic approaches, flexible governance frameworks, and collaborative networks to foster circular innovation at the regional level.

The integration of circular economy into regional innovation systems emerges as a strategic pathway for achieving sustainable territorial development. However, this process requires overcoming institutional limitations, strengthening collaborative networks, and introducing public policy instruments specifically designed to support this synergy. This review provides critical elements to help answer the article’s central research question: How can the circular economy be integrated into regional innovation systems as a strategy for sustainable territorial development?

3. Methodology

This study is based on a qualitative-comprehensive approach aimed at identifying the dynamics, barriers, and opportunities that emerge when seeking to articulate the circular economy (CE) with regional innovation systems (RIS) in Latin American contexts. Rather than starting from a structured theoretical review, an empirical, participatory, and strategic mapping approach was adopted to capture the complexity of institutional, political, and social relationships involved in these processes.

Method: Structural Strategic Mapping (SSM)

The core method used in this study is Structural Strategic Mapping (SSM), a participatory analysis tool developed by [Godet, M. \(2007\)](#) that enables the visualization and interpretation of relationships among strategic variables in a complex system. This technique is particularly useful for understanding the positioning, influence, and dependence of

factors such as public policy, technological capabilities, sustainability culture, and productive infrastructure, among others.

SSM was applied in three Latin American regions selected for their advancement in sustainability and innovation strategies: Colombia, Mexico, and Peru.

Fieldwork Stages

Identification and Validation of Variables: An institutional ethnography was conducted to identify key variables involved in CE–RIS articulation in each region. This stage included:

- Review of local policies and economic development plans.
- Direct observation of pilot projects and innovation centers.
- Participatory dialogues with local actors (20 participants), including innovation managers, public officials, business representatives, and environmental NGOs.

Influence–Dependence Matrix: Based on the identified strategic variables (n=18), an influence–dependence matrix was developed to classify factors according to their impact on the territorial system. This matrix was processed using Micmac software (Matrice d’Impacts Croisés Multiplication Appliquée à un Classement), which allowed the generation of structural maps for each region.

Influence–Dependence Matrix (SSM)

	Technological Capacity	Sustainability Culture	CE Innovation Financing	Productive Infrastructure	Talent Development	Public–Private Cooperation	Environmental Regulation	Political Will
Technological Capacity	0	1	2	3	0	1	2	3
Sustainability Culture	3	0	1	2	3	0	1	2
CE Innovation Financing	2	3	0	1	2	3	0	1
Productive Infrastructure	1	2	3	0	1	2	3	0
Talent Development	0	1	2	3	0	1	2	3
Public–Private Cooperation	3	0	1	2	3	0	1	2
Environmental Regulation	2	3	0	1	2	3	0	1
Political Will	1	2	3	0	1	2	3	0

Source: Authors’ elaboration using SSM methodology, 2024.

Structural Comparative Analysis: Once the structural maps for each region were generated, a comparative analysis was carried out to identify:

- Common driving variables (transversal enabling factors).
- Risk or uncertainty variables.
- Potential CE–RIS articulation scenarios.

These results were validated with local stakeholders through **online focus groups** held in each territory.

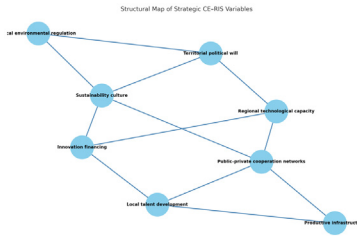


Figure 1. Structural Map of Strategic Variables (CE–RIS)
Source: Authors' elaboration, 2024.

The use of Structural Strategic Mapping (SSM) allowed for the construction of a systemic and situated vision of how circular economy dimensions interact with regional innovation structures. Unlike theoretical or bibliographic reviews, this approach provides empirical evidence based on the perceptions, experiences, and collective knowledge of territorial actors. Moreover, the comparative analysis across regions with different institutional trajectories offers key insights to design differentiated strategies for sustainable territorial development.

4. Results

The research findings are structured into three main analytical dimensions: (i) territorial interdependence patterns, (ii) critical success factors in CE–RIS integration, and (iii) contextual conditions for circular transition within regional innovation ecosystems.

These dimensions emerged from the structural analysis and from contrasting territorial perceptions collected through workshops and interviews.

Territorial Interdependence Patterns

The structural maps of the three regions reveal a high interdependence pattern among strategic variables, with a particular emphasis on technology, sustainability, and cooperation networks. In all three regions, the variables “territorial political will,” “local talent development,” and “innovation financing” consistently appear as linking factors—they both influence and are influenced by other variables, acting as essential connectors for activating sustainable circular dynamics.

Within the framework of the comparative structural analysis, a radar chart was developed to visualize how the main strategic variables related to the integration between circular economy and regional innovation systems manifest across three Latin American regions: Antioquia (Colombia), Jalisco (Mexico), and Lima (Peru). This chart helps to identify differences in the intensity of influence and dependence of each variable according to territorial context and highlights distinct patterns of institutional articulation, technological capacities, infrastructure, sustainability culture, and governance. The visualization provides an empirical basis for interpreting how each region organizes its enabling conditions for a successful circular transition.

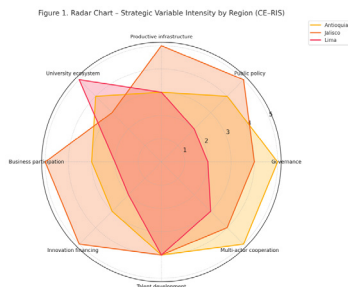


Figure 1. Radar Chart – Strategic Variable Intensity by Region (CE–RIS)
Source: Authors' elaboration

The radar chart enables a comparison of how strategic variables behave in terms of influence and dependence across the three analyzed regions: Antioquia (Colombia), Jalisco (Mexico), and Lima (Peru). Antioquia shows strong values in “territorial political will” and “public–private cooperation networks”, indicating a collaborative institutional ecosystem with solid articulation among public and private actors. In Jalisco, “productive infrastructure” and access to “innovation

financing” stand out, reflecting greater maturity in connecting economic development with sustainability. Conversely, Lima presents more moderate scores across most variables, with relative strength in “local talent development” and “sustainability culture”, suggesting a context with dispersed initiatives, primarily led by academia and civil society.

This comparison reveals that the articulation between circular economy and regional innovation models is strongly conditioned by each region’s institutional capacity, resource availability, and political will. Each territory requires tailored intervention strategies that reflect its starting point in terms of structural development and innovation ecosystem maturity. Overall, the chart supports the need for territorialized, adaptive, and multi-actor approaches to advance the transition toward sustainable circular models.

The visualization also highlights that while the regions share high-impact strategic factors, the intensity and configuration of these relationships vary. For instance, Jalisco exhibits a higher structural weight in “productive infrastructure”, while “public–private cooperation” is more prominent in Antioquia. In contrast, Lima shows institutional weaknesses, shifting responsibility to universities and civil society initiatives.

This pattern suggests that there is no single pathway to integrating CE and RIS; rather, it depends on the articulation among actors, institutional readiness, and the sustainability culture unique to each territory. Intervention strategies must be both place-based and adaptive.

Critical Success Factors in CE–RIS Integration

Based on the analysis of interviews and regional policy documents, five critical factors were identified as enablers of convergence between circular economy and regional innovation in the cases studied:

- a. Coordinated multi-actor governance (observed in Antioquia).
- b. Systemic public policy frameworks (notable progress in Jalisco).
- c. Access to climate finance and innovation funds.
- d. Proactive university ecosystems with open innovation laboratories.
- e. Business participation in industrial symbiosis networks.

Table 1. Critical Success Factors by Region

Region	Multi-actor Governance	Public Policy	Financing	University Ecosystem	Business Participation
Antioquia	✓✓✓	✓✓	✓	✓✓✓	✓✓
Jalisco	✓✓	✓✓✓	✓✓✓	✓✓	✓✓✓
Lima	✓	✓	✓	✓✓✓	✓

Legend: ✓✓✓ = Strong / ✓✓ = Moderate / ✓ = Weak

Source: Authors’ elaboration, 2024

This table summarizes the development levels of each critical factor across the three regions. Jalisco stands out for its comprehensive public policy and robust financing mechanisms. Antioquia leads in collaborative governance, while Lima relies more heavily on university ecosystems due to weaker public institutional support.

The integration of CE and RIS does not depend exclusively on institutional design but rather on the capacity to build collaborative regional ecosystems with incentives and resources to promote green innovation. The density of relationships among actors is more impactful than regulatory sophistication alone.

Contextual Conditions for Circular Transition

Through data triangulation, the following enabling conditions were identified as factors that positively or negatively influence the transition toward regional circular economy models:

Positive Enablers:

- Existence of technology transfer centers.
- A culture of open innovation within universities.

- International support and technical cooperation.

Limiting Conditions:

- Institutional fragmentation.
- Lack of impact evaluation indicators for circularity.
- Low public awareness of the role of responsible consumption.

To better understand the perceptions, barriers, and opportunities associated with integrating circular economy principles into regional innovation systems, a semantic analysis of interviews and field observations was conducted. Based on this analysis, a word cloud was generated, reflecting the most frequently cited terms and revealing the structuring concepts that shape the narrative of circular transition in each territory.



Figure 2. Word Cloud of Key Terms Emerging from Interviews (by Frequency)

Source: Authors' elaboration, 2024

The word cloud reveals that the most frequently mentioned terms are related to cooperation, open innovation, and innovation laboratories, reinforcing the idea that collaborative learning and interinstitutional articulation are fundamental pillars for advancing toward sustainable models. At the same time, concepts such as institutional fragmentation and political will emerge, pointing to the structural and cultural challenges faced by territories in implementing effective circular policies. Other frequent terms—such as environmental education, green financing, and clean technology—highlight key areas where transformational action is most urgently expected.

The most prominent concepts indicate that the circular transition within RIS is shaped by notions of cooperation, technology transfer, and the need to reconfigure relationships among actors. Barriers related to governance and institutional culture also emerge strongly.

The findings suggest that the success of the circular transition requires not only minimum structural conditions, but also a cultural transformation in organizational dynamics, the design of economic incentives, and informed social participation.

Ultimately, the results demonstrate that the articulation between circular economy and regional innovation systems cannot be conceived as a linear or homogeneous process. Rather, it must be understood as a complex, interdependent, and deeply contextualized territorial dynamic. The empirical evidence from Antioquia, Jalisco, and Lima reveals common patterns in enabling factors—such as multi-actor cooperation and talent development—but also shows divergences in institutional maturity, governance capacity, and access to green financing mechanisms. The convergence of highly interconnected strategic variables, identified through structural analysis and confirmed in interviews, underscores the need for integrated territorial approaches that overcome institutional fragmentation and foster resilient innovation environments. These findings lay the groundwork for a critical discussion on how current theoretical frameworks align with the Latin American reality and how sustainable and adaptive transition pathways can be designed from the local to the global scale.

5. Discussion

The convergence between circular economy (CE) and regional innovation systems (RIS) represents a unique opportunity to redirect territorial development toward sustainable and inclusive frameworks. However, it requires overcoming institutional and cultural barriers and strengthening public policies that integrate sustainability as a cross-cutting axis of innovation (Bai et al. 2021). This article suggests adopting adaptive and multi-actor governance frameworks that promote the co-creation of solutions and the transfer of circular knowledge.

The findings presented in the previous section demonstrate that the integration between CE and RIS is possible, yet it is highly dependent on the institutional, cultural, and political configurations of each territory. This conclusion supports the arguments of authors such as [Domenech & Bahn-Walkowiak. \(2019\)](#) and [Callegari et al. \(2023\)](#), who emphasize that progress toward circular systems requires adaptive governance and strong multi-stakeholder coordination. In this regard, the concept of territorialized sustainability becomes relevant, as CE cannot be understood as a universal formula, but rather as a situated practice, adapted to the capacities and conditions of each regional ecosystem.

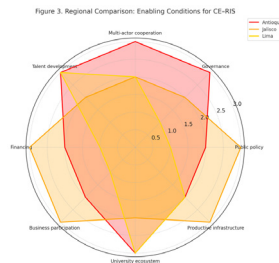


Figure 3. Regional Comparison of Enabling Conditions for CE–RIS
Source: Authors' elaboration, 2024

Jalisco presents the most balanced and robust profile, standing out in public policy, productive infrastructure, financing, and business participation, which suggests a strong articulation between the state, the productive sector, and science. Antioquia, in turn, leads in governance, multi-actor cooperation, and talent development, with strong institutional commitment that compensates for certain limitations in infrastructure and financing. Lima, although it has a highly active university ecosystem, shows significant weaknesses in governance, public policy, and financing, which limits its ability to consolidate a structural circular transition.

The chart confirms that CE–RIS integration depends on multiple dimensions that must be strengthened simultaneously. It is not enough to have motivated stakeholders or well-written policies; it is necessary to develop a balanced and articulated capacity architecture adapted to local conditions.

From the perspective of regional innovation models, the findings support what was proposed by [Cooke et al. \(1997\)](#) and [Sheim & Gertler. \(2005\)](#): innovation is not merely a product of available resources but emerges from institutional relationships, local culture, and governance structures. In regions like Antioquia and Jalisco, where institutional trajectories are more consolidated, higher levels of circular integration are observed. This aligns with [Rodríguez-Pose. \(2013\)](#), who emphasized the relationship between institutional quality and territorial innovation. In contrast, the case of Lima demonstrates how institutional fragmentation and fragile public policy hinder the region's ability to generate circular synergies, despite its academic dynamism.

A key finding is the central role of linking variables identified through Structural Strategic Mapping (SSM). Elements such as “political will,” “talent development,” and “public–private cooperation” have a dual nature: they are both drivers of change and dependent on the broader institutional and social environment. This duality confirms [Pauliuk. \(2018\)](#) argument on the need for systemic approaches that integrate technology, governance, and cultural change. Moreover, the word cloud reveals that notions such as “innovation laboratories,” “triple helix,” and “environmental education” are deeply rooted in territorial discourses, suggesting the presence of symbolic infrastructure favorable to change, although a more robust institutional framework is still needed to consolidate it.

Finally, this discussion invites us to rethink current public policy and territorial planning approaches. While international literature offers solid reference frameworks—such as the CE principles proposed by [Geissdoerfer et al. \(2017\)](#) and [Bocken et al. \(2016\)](#)—it is necessary to reinterpret these within the Latin American context, which is characterized by institutional asymmetries, structural inequality, and high dependency on extractive sectors. Integrating CE into RIS in Latin America requires more than replicating best practices: it demands the construction of new territorial agreements, the fostering of an open innovation culture, and the strengthening of the social fabric as the foundation for circular resilience.

Conclusions

Circular economy can be effectively integrated into regional innovation systems, provided that minimum institutional

conditions, cross-sectoral cooperation structures, and an adaptive governance framework are in place. This integration is neither automatic nor homogeneous; rather, it depends on territorial factors such as sustainability culture, available financing, and the quality of relationships among ecosystem actors.

The cases analyzed—Antioquia, Jalisco, and Lima—reveal distinct yet complementary trajectories. Antioquia stands out for its multi-actor governance, Jalisco for its systemic public policy, and Lima for the strength of its universities. However, all three face common challenges, including institutional fragmentation, a lack of circular evaluation indicators, and the need to transform organizational culture.

The structural analysis conducted through Structural Strategic Mapping (SSM) confirms that the key variables in the CE–RIS system are relational in nature—that is, they are both highly influential and highly dependent. This requires the design of integrated interventions, rather than sectoral or unidirectional approaches.

The answer to the research question—How can the circular economy be integrated into regional innovation systems as a strategy for sustainable territorial development?—demands the simultaneous activation of three core dimensions: institutional capacity, relational density, and a shared vision of development.

Strategic Recommendations

For local and regional governments:

- Develop integrated public policies that align sustainability, innovation, and productive development.
- Establish technical units to support the circular transition and link them to territorial observatories.
- Invest in the training of specialized talent in circular economy and innovation generation.

For universities and R&D centers:

- Promote interdisciplinary programs that integrate sustainability, economics, and technology.
- Strengthen open innovation laboratories as platforms to prototype circular solutions.
- Actively engage in regional and global circular economy networks.

For companies and industrial clusters:

- Encourage the adoption of circular business models (remanufacturing, reuse, eco-design).
- Participate in industrial symbiosis networks to share resources, waste, and knowledge.
- Measure and report the circular impact of operations to gain access to green investment and incentives.

For international cooperation organizations:

- Support pilot projects in territories with circular potential, prioritizing local leadership.
- Finance green and technological infrastructure to strengthen circular innovation ecosystems.
- Promote regional platforms for sharing good practices and lessons learned.

Credit authorship contribution statement

The author was solely responsible for the conceptualization, methodology, data collection, analysis, writing, and revision of this manuscript.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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