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Research Article

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Abstract

Non-technical summary. Transitioning to a circular economy (CE) – where materials are reused rather than discarded – is a key sustainability challenge in Latin America and the Caribbean (LAC). Quality infrastructure (QI), encompassing standards, metrology, and certification, is essential to validate circular claims and build market trust. This study shows that when QI organisations actively collaborate across borders, they innovate faster and develop more services for the CE. Regional partnerships and inclusive networks, especially those led by women and bridging organisations, are critical to driving this transition beyond national boundaries.

Technical summary. This paper examines how collaborative networks between QI and CE actors drive innovation in LAC. Drawing on empirical evidence from the regional Quality Infrastructure for the Circular Economy in Latin America and the Caribbean (QI4CE) project (2020–2024), which involved 150 QI organisations and 650 CE stakeholders across three sectors (plastics, agri-food, and construction), the study applies longitudinal social network analysis to test three hypotheses. Results confirm that baseline QI–CE networks were fragmented and nationally siloed (H1). Intensive participation in regional project activities led to fivefold network growth and significantly increased organisational heterogeneity, strongly predicting improvements in metrology, standardisation, and conformity assessment service innovation (H2). Organisations with superior territorial coordination and transnational networking capabilities, particularly regional connector bodies such as the Quality Infrastructure Council of the Americas, demonstrated the highest innovation outcomes (H3). Female leadership emerged as an additional driver of inclusive network development. The findings demonstrate that structured, data-driven investment in regional collaboration mechanisms accelerates CE adoption. Policymakers, international development organisations, and QI bodies should prioritise cross-border partnerships and inclusive governance to realise sustainable circular transitions.

Social media summary. Regional QI networks drive CE innovation in Latin America. Collaboration works – data prove it.

1. Introduction

In Latin America and the Caribbean (LAC), the circular economy (CE) is gaining momentum as a strategic response to the social and environmental weaknesses of the traditional linear economic model. High-level political attention and new national policies have emerged, reflecting a shared regional vision emphasising resilience, inclusivity, and sustainable development. The transition to circularity is seen as especially urgent after the COVID-19 pandemic exposed vulnerabilities in global supply chains and natural resource depletion throughout the region. Adoption of Industry 4.0 technologies is recognised as essential to making circular business models profitable and environmentally viable, but investment in research and development remains low compared to global averages (Chatham House, 2020, 14). For a just and sustainable transition, emphasis is placed on social innovation, equitable benefit distribution, transparent governance, and the incorporation of circular principles in priority sectors such as mining, waste management, and the bioeconomy (Chatham House, 2020, 26). Progress depends on financing and practical cooperation across national borders and active engagement by governments, businesses, and civil society (Ellen MacArthur Foundation, 2021, 43; UNEP, 2023, 91; World Economic Forum, 2014).

The CE has emerged as a crucial strategy for addressing environmental and economic challenges in LAC, with quality infrastructure (QI) posited as a foundational driver to support a sustainable and reliable transition. Although the concept of CE has become more clearly defined over recent decades and is now widely seen as an umbrella framework

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(Blomsma & Brennan, 2017), there remain significant challenges regarding its practical scope, understanding, and implementation – particularly for small- and medium-sized enterprises in the region. Importantly, CE adopts a regenerative perspective, seeking a balanced and optimised use of resources to deliver positive social, economic, and environmental outcomes.

The transition towards a CE is increasingly recognised as essential for achieving the region's sustainability goals; however, it depends fundamentally on trust among economic, social, and political actors in claims of circularity. Society must be confident that products, materials, and processes genuinely adhere to circular principles. A major threat to this trust is the phenomenon of 'circular washing' (Sustainability Directory, 2025), where circular practices are misrepresented or exaggerated. In response, QI services – including standardised measurements, certifications, laboratory testing, accreditation, and inspection – play a vital role in ensuring trust and traceability and provide objective, reliable evidence. By verifying and validating claims, QI services ensure that only truly circular products, materials, and activities are recognised and rewarded, thus safeguarding both the credibility of the transition and the systemic benefits it promises.

In this context, the quality, safety, and environmental soundness of goods, services, and processes are necessary for the effective functioning of domestic markets, and their international recognition is essential to enable access to foreign markets. This is a fundamental element in promoting and sustaining economic development, as well as environmental and social well-being. This is achieved through metrology, standardisation, accreditation, conformity assessment, and market surveillance (UNIDO, 2017).

QI is operationalised through National Quality Systems (NQS), which play a crucial role in the transition to CE by providing an institutional framework that encourages competitiveness in enterprises and establishes regulatory frameworks for the quality of products and services that protect people and ecosystems.

NQS are made up of standardisation, metrology, and accreditation organisations, each working as elements of a living system. They guarantee technical competence, impartiality and independence to establish themselves as competent service providers for the private sector and facilitate free trade (Harmes-Liedtke, 2024a; Harmes-Liedtke and Stamm, 2021).

One of the greatest challenges of the CE is to ensure that its application is consolidated over time, moving from a trend to an economic system capable of creating value through the flows of existing resources. This can be achieved by providing harmonised terminology, confidence in measurements, traceability of information, and more competitive products, among other benefits.

While the need to articulate these two systems is clear, it is a challenge due to the novelty and dynamism of CE and the difficulties in generating innovations in QI systems, which tend to be oriented towards traditional or consolidated activities (Harmes-Liedtke et al., 2024b). This process and need for articulation do not result from a sequence of linearly planned technical procedures, but rather from a social process in which it is necessary to develop knowledge management, interaction, and cooperation between its parts to achieve results.

This research proposes to investigate the processes of articulation between QI and CE systems, and particularly the role played by social dynamics in these processes at the level of cooperation networks. The data presented are based on the experiences of the project 'Quality Infrastructure for the Circular Economy in Latin America and the Caribbean' (QI4CE) between 2020 and 2024.

This research project examines the relationship between QI and the CE in LAC. It focuses on the role of social dynamics in cooperation networks and uses data from the QI4CE project (2020–2024).

Three hypotheses are tested:

H1: Initially, interactions and cooperation between QI and CE systems were limited in the countries under study.

H2: Intensive participation in the regional cooperation project activities builds larger, more diverse organisational networks that improve innovative performance.

H3: Organisations with stronger capabilities in territorial coordination and transnational networking achieve better innovation outcomes.

These hypotheses will guide the analysis, with a more detailed discussion provided in later chapters.

As Kirchherr et al. (2017) argue, the CE can be described as an economic system based on business models that replace the concept of end-of-life with the reduction, reuse, recycling, and recovery of materials in production, distribution, and consumption processes. It operates at the micro level (products, companies, and consumers), the meso level (eco-industrial parks), and the macro level (city, region, nation, and beyond), with the aim of achieving sustainable development, which implies creating environmental quality, economic prosperity, and social equity for the benefit of current and future generations. Through the compilation, codification, and analysis of 114 definitions of the CE, the authors identified that the economic dimension is recognised as a fundamental aspect and is reiterated in the definitions analysed.

ISO 59004:2024 is the international standard on CE terminology and part of the ISO 59000 family of standards, which provides practical guidance for implementing the CE in organisations regardless of their size, geographical location, or sector (Harmes-Liedtke and Canelas-Santiesteban, 2024; International Organization for Standardization, 2024). ISO 59004:2024 defines the CE as 'an economic system that uses a systemic approach to maintain a circular flow of resources by recovering, retaining, or adding to their value, while contributing to sustainable development'. The standard provides a universal lexicon, foundational principles, and detailed guidance for organisations to transition from a linear, take-make-dispose model towards the sustainable management and renewal of natural resources in pursuit of the United Nations Agenda 2030 for Sustainable Development.

ISO 59004:2024 emphasises six interlinked principles:

- Systems thinking (long-term, lifecycle perspective)
- Value creation (efficient resource use)
- Value sharing (collaboration across value networks)
- Resource stewardship (managing resource flows by closing, slowing, or narrowing loops)
- Resource traceability (ensuring information is shared transparently)
- Ecosystem resilience (regenerating ecosystems and biodiversity).

In summary, ISO 59004:2024 positions the CE as a holistic system focused on sustainable value, inclusivity, and resilience, guiding organisations to move beyond conventional practices to circular and regenerative approaches.

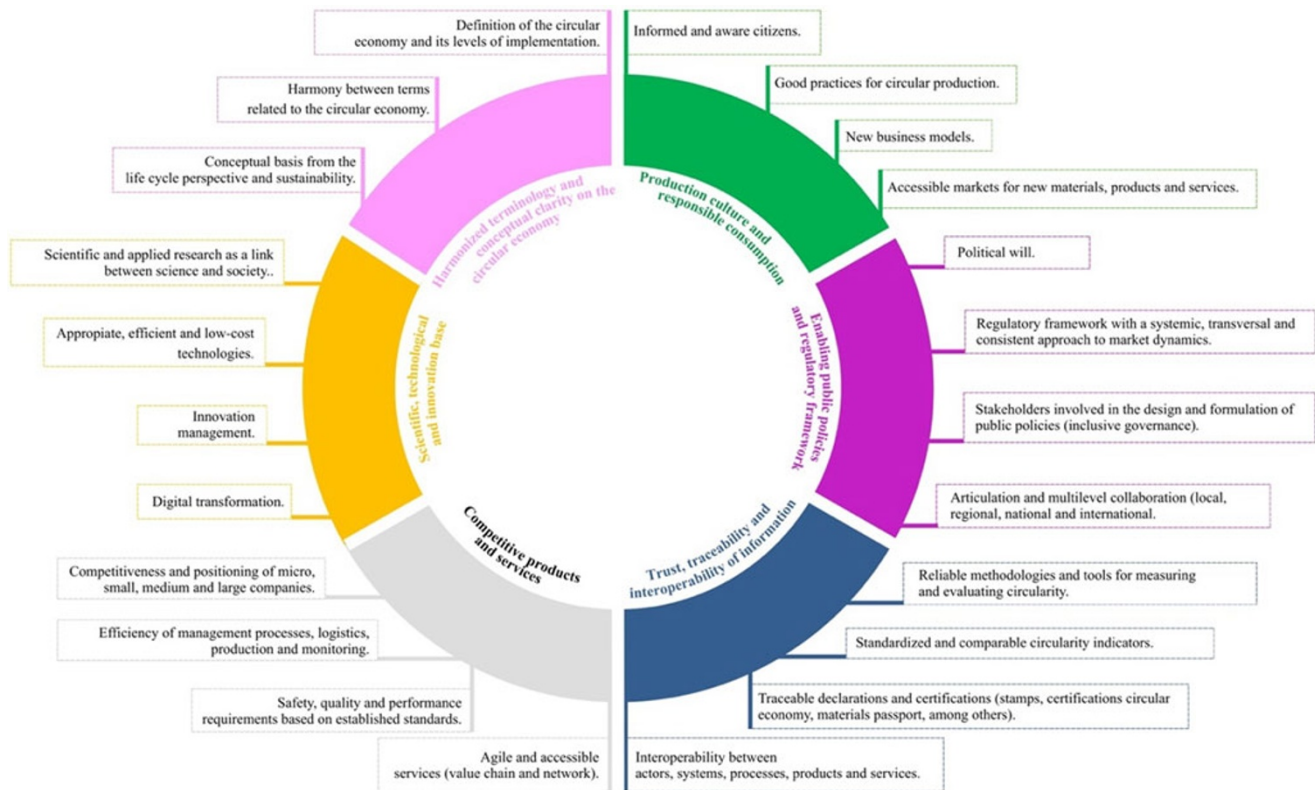


Figure 1. Circular economy needs that can be supported by quality infrastructure services through standardisation, metrology, accreditation, and conformity assessment. Source: Quality Infrastructure for the Circular Economy in Latin America and the Caribbean (pp. 64–65) by Canelas-Santiesteban et al. (2022).

The study ‘Quality Infrastructure for the Circular Economy in Latin America and the Caribbean’ (Canelas-Santiesteban et al., 2022) identifies six specific needs presented by the CE in the region to which QI can contribute through its various services (Fig. 1). Gonçalves et al. (2014) argue that sectors such as consumer and environmental protection, food safety, drinking water, efficient energy use, commercial transactions, and technological innovation all depend on measurements, standards, and technical regulations. According to the author, these elements are essential for supporting industry and providing the scientific backing needed to ensure trust in areas like fraud protection for weight, volume, quality, and products.

Today, the contribution of QI and the services it offers, such as measurements, technical standards, testing, calibrations, market surveillance, and certifications, play an increasingly important role in the design of public policies, national CE strategies, and strategic project management.

For this reason, the Quality Infrastructure Council of the Americas (QICA) has made various efforts to coordinate both systems, including a strategic roadmap (UNIDO, 2017) in which, as a regional organisation, it seeks to promote collaborative actions between national organisations associated with sustainable development initiatives.

The study is based on three research hypotheses: The first hypothesis (H1) proposes that, between the CE and QI in the countries studied, there was a low level of interaction and cooperation at the beginning of the process.

However, there was a need to develop and capitalise on further experiences regarding the benefits and impact that QI services can offer to innovative developments for circularity, including

documentation on the use of standards, products subject to certification, and their interaction. This is where the creation of networks becomes relevant to promote coordination and encourage cooperation in the development of innovations.

The importance of strengthening social processes for sustainable development and innovation has been highlighted by various studies. A series of studies highlights, for example, the importance of cooperation between users and stakeholders for the co-creation of new products and services. This collaboration from the outset promotes mutual learning and is key to ensuring the adoption and impact of new developments (Abhari et al., 2020; Gerli et al., 2020; Kohlgrüber et al., 2021; Lettice & Parekh, 2010; Marschall, 2018).

Other research highlights that for this cooperation to be possible, it is important that certain cultural conditions exist or are developed, such as mutual trust or shared common norms (Gupta et al., 2020; Meijer & Thaens, 2018; Oeij et al., 2019; Pel et al., 2020; Tverskoi et al., 2022). Other studies also emphasise the role of agents (public and private) who have the skills to lead coordination and cooperation processes (Battisti, 2019; Morais-Da-Silva et al., 2021; Vezina et al., 2019; Xie et al., 2023).

Finally, and given its importance for this research, numerous studies highlight the structural role of networks in mobilising resources and knowledge and facilitating the above-mentioned aspects to be functional to innovation (Alfaraz & Tully, 2024; Marques and Manzanares, 2022; Tsai & Ghoshal, 1998; Van Wijk et al., 2018; Young, 2011; Zhou et al., 2025).

Building on these findings, the second hypothesis (H2) posits that greater intensity of participation in activities organised by cooperation projects will lead to an increase in both the size and heterogeneity of organisational networks. This expansion and

Table 1. Number of organisations and organisational types in the universe and the sample analysed (2021–2023)

	Project participants (universe)			Sample			Organisations in the networks		
	2021	2022	2023	2021	2022	2023	2021	2022	2023
Total organisations	154	274	806	57	116	109	291	460	634
QI organisations (standardisation, accreditation, metrology, conformity assessment)	38.96%	38.32%	18.86%	68.42%	58.62%	52.29%	19.93%	20.87%	19.09%
EC organisations (companies, business associations)	27.27%	30.29%	44.04%	14.04%	16.38%	24.77%	37.80%	36.09%	38.01%
Support organisations (governments, universities, international organisations, etc.)	33.77%	31.39%	37.10%	17.54%	25.00%	22.94%	42.27%	43.04%	42.90%

Source: Own elaboration, 2024.

diversification are expected to foster improved innovative performance, as a more varied network structure enables organisations to access diverse knowledge and collaboration opportunities, thereby stimulating the development of new solutions and services.

Our third hypothesis (H3) states that the ability to lead coordination processes at the national level, along with the capacity to establish transnational linkages, is essential for achieving meaningful innovation outcomes. Because innovation is driven by social dynamics, existing research indicates that the benefits of collaborative efforts may become concentrated within a limited set of organisations or individuals. Thus, H3 suggests that those actors most effective in facilitating territorial coordination and developing cross-border networks are positioned to generate the greatest impact in advancing innovative practices.

2. Methodology

2.1. Data sources

The empirical basis of this study is the process carried out by the regional project called QI4CE implemented by the Physikalisch-Technische Bundesanstalt (PTB) in coordination with the Organisation of American States (OAS), regional QI organisations such as COPANT, IAAC, and SIM, and national institutes, and co-financed by the German Federal Ministry for Economic Cooperation and Development (BMZ).¹

The QI4CE project, implemented between 2020 and 2024, involved the participation of 150 organisations linked to QI and 650 companies and organisations in the field of CE or that support it (governments, universities, etc.). Its objective was to promote cooperation between regional QI organisations and their national members in the field of CE to strengthen their technical skills and raise awareness among CE stakeholders of the benefits of QI.

During the implementation period of the regional project, various awareness-raising and training activities (training courses, workshops, and events) were carried out, but methodologies focusing on innovation and collaboration were also used, such as CALIDENA,² CABUREK,³ as well as the QI4CE Fund initiative to promote regional cooperation.

The QI4CE project focused on three sectors: plastics, agri-food, and construction, which resulted in the development of QI services in line with the market needs of each country. These were promoted

and developed by national QI organisations in coordination with actors and organisations working on CE issues.

With the aim of recording, visualising, and analysing the structure of the emerging network between QI and CE organisations, social network analysis (SNA) was chosen as the monitoring tool for the QI4CE project. SNA was conducted annually and provided empirical evidence on the evolution of collaboration networks between QI and CE, as well as on the effects of project activities evidenced by changes in the size and nature of links during the project's implementation period. Key concepts and SNA metrics used in the study are detailed in Table 2.

The survey to build the networks and collect data related to their innovative performance was conducted over 3 years (2021–2023), using a questionnaire addressed to all QI4CE project participants. The survey, conducted using LimeSurvey included questions about the characteristics of the organisations, the links between them, and the innovation processes developed. This study uses a longitudinal SNA. The number of participating organisations increased over the 3-year period, according to their participation in project activities or mentions as relevant stakeholders by representatives of the surveyed organisations. The continuity of organisational participation over time was recorded. The analysis examines the evolution and overall structural changes of the cooperation network, focusing on tie dynamics, such as strengthening, weakening, or forming new connections within the same network.

Any organisation with at least one representative who had attended an activity, either in person or virtually, organised by the regional project was considered a project participant.

As a result of the surveys, Table 1 allows us to observe the composition of the project participants during the 3 years surveyed, the size of the sample surveyed, and the size of the network of institutions reached based on the mentions made by the respondents. In this way, we can observe the evolution of participation in the project and the composition of the samples surveyed each year. On the other hand, although these surveys include a significant representation of QI organisations, the identified networks are similar in size and composition to the universe of each year.

2.2. Research method

SNA was selected as the primary research method because it effectively captures the social dynamics of interaction, cooperation,

Table 2. Concepts and metrics used for social network analysis

Graph or network	Constructed from the inventory of nodes and the set of direct interactions between them, represented through links or vertices .
Nodes	These are the social units or components of a system (individuals, groups, or organisations). In this case, organisations have been considered as the unit of analysis.
Vertex/link	Represents the interaction between nodes (organisations). For this study, we consider the link established between one organisation and another through maintaining contact, providing a service, cooperating through innovation, or being a reference organisation.
Size	Number of actors linked to a network.
Density	The density of a network is calculated as the sum of the values of the links divided by the number of possible links.
<i>Degree</i> centrality	Number of connections or vertices of a node (Freeman, 1978). In asymmetric networks, where the 'initiation' does not coincide with the 'reception' of relationships (e.g. one actor says they know another, but the other does not mention it), the 'outdegree' indicates the number of direct relationships originating in an organisation, while the 'indegree' reflects the number of ties received from other organisations. It can also be understood as the size of each agent's network.
Index of qualitative variation (IQV)	This is a standardised version of Blaug's heterogeneity index that measures the degree of variety in each agent's network. It is calculated as 1 minus the sum of the squares of the proportions of each value of a categorical variable defined for the individual network. This index is accompanied by a breakdown of the proportion of links that the actor has with each type of actor.
Intensity of participation in events	This is measured based on the number of awareness-raising and training events in which the organisation has participated.
Intensity of participation in projects	This is measured based on the number of projects in which the organisation has participated.

Source: Own elaboration.

and knowledge management, which are essential for articulating quality infrastructure (QI) and CE systems. Traditional linear approaches are unable to address these dynamics adequately. This choice is also consistent with the study's hypotheses regarding network evolution, since SNA reveals relational structures, stakeholder centrality, and innovation pathways within collaborative settings. Examples of such settings can be seen in the QI4CE project, which involved 150 QI organisations and 650 CE stakeholders across LAC.

SNA is a set of tools that allow the analysis of the network of links between social agents (individuals, organisations, etc.) (Barabasi, 2016; Haythornthwaite, 1996; Sanz-Menéndez, 2003). In recent decades, it has gained recognition for its ability to visualise and analyse social relationship structures, establishing itself as a robust tool based on mathematical, statistical, and computational approaches (Wasserman & Faust, 1999).

Its potential for studying processes, such as those considered here, can be seen in recent literature. For example, a set of studies uses SNA to map actors and detect flows of resources and knowledge in innovation and sustainable development processes to identify bottlenecks, key actors, and opportunities to improve the effectiveness of networks, optimise the flow of knowledge, and drive innovation (Chen et al., 2018; Cross et al., 2001; Gubbins & Dooley, 2014; Guerrero-Ocampo & Díaz-Puente, 2023; Kolleck, 2013; Leenders & Dolfsma, 2016; Liu et al., 2021; Niang et al., 2022; Van der Valk & Gijssbers, 2010). Other research analyses how networks between different types of organisations (companies, universities, government agencies) influence the degree of innovation in production systems (Alberti et al., 2021; Dahesh et al., 2020; Giuliani & Pietrobelli, 2011; Shi & Xiao, 2024). Some studies also identify the limitations of network phenomena, which can exacerbate pre-existing inequalities and concentrate benefits among key players (Giuliani et al., 2019; Hermans et al., 2017; M. Li et al., 2019; Morrison, 2008; Woods et al., 2019).

SNA allows the 'map' of connections between agents to be reconstructed through a graph resulting from the inventory of social units or components of a system, called **nodes**, and the set of direct interactions between them represented through links or **vertices**, allowing the relationship between units to be visualised.

In this case, QI nodes included metrology institutes, accreditation bodies, conformity assessment bodies (CABs), and standardisation institutes, as well as independent professionals and regional organisations that carry out activities in support of QI bodies. The CE nodes include organisations and/or independent professionals linked to the CE, whether they are companies, support institutions (SIs), or regional bodies.

The forms of interaction (vertices) were classified by their part in Contact Networks (which actors know each other and have interacted in the last year); Services (which actors have provided and/or received QI services in the last year); and Innovation (which actors have worked together in the last year to adapt or develop new services).

Specific software programs were used to apply the SNA, in particular UCINET (Borgatti et al., 2002) and Gephi (Bastian et al., 2009).

Based on the metrics mentioned above, which have served as the basis for SNA, this study also contributes on several levels to the literature on QI and CE, as it proposes an empirical study of the links between both subsystems on an international scale.

In practice, SNA was applied to empirical data from 2021 to 2023 to map the evolution of QI–CE networks in the plastics, agri-food, and construction sectors. This was achieved using metrics such as centrality, density, and tie growth.

The QI has been approached as a field of study relatively recently. For this reason, various authors point to gaps in research in this area, both in terms of its focus, which often omits the systemic nature of QI and its scope, which is mostly national or subnational.⁴ Added to these limitations are the lack of a general

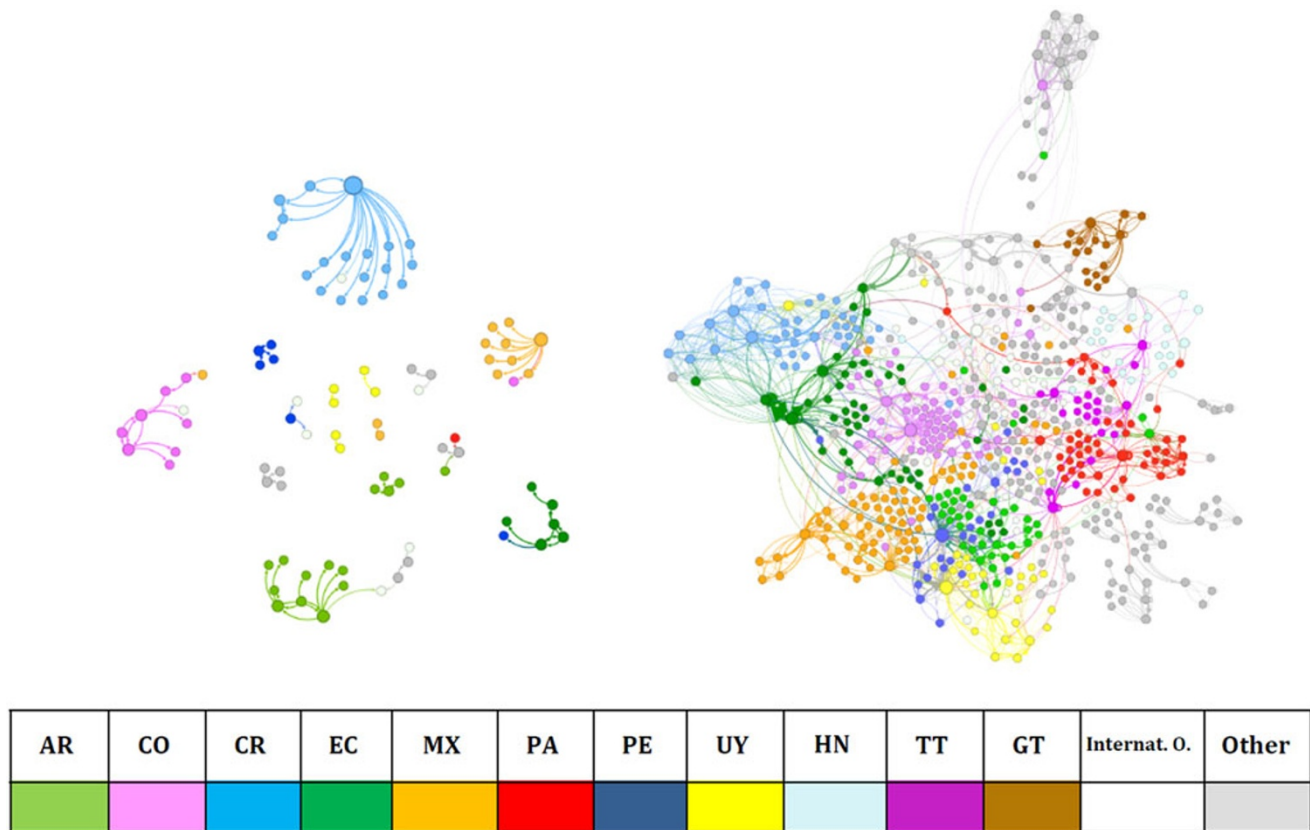


Figure 2. Evolution of quality infrastructure and circular economy innovation networks between 2021 and 2023.

Source: Own elaboration, 2024. The acronyms stand for country names. Argentina (AR), Colombia (CO), Costa Rica (CR), Ecuador (EC), Mexico (MX), Panama (PA), Peru (PE), Uruguay, Honduras (HN), Trinidad and Tobago (TT), as well as international organisations and others.

conceptual model and the limited availability of data (Blind et al., 2026). Among the works that seek to map or analyse QI, theoretical or normative descriptions predominate (Gutiérrez Ocegueda & Gutiérrez Aceves, 2024; Rab, Yadav, Jaiswal, et al., 2021; Rab et al., 2021) the use of traditional outcome indicators (Carvalho Dos Reis & Ludovico de Almeida, 2021; Reis and Almeida, 2021; Rab & Brown, 2023; Trajković et al., 2025). Although most of these authors emphasise the value of networks and cooperative links, they do not apply specific methodologies to study them (Blind, 2024; Blind et al., 2018; Kellermann, 2019; Rab, Yadav, Jaiswal, et al., 2021).

The field of CE offers a broader view in terms of the number of studies. However, while some include network analyses like the one proposed here, they tend to remain limited by the same constraints mentioned earlier, especially their narrow focus on local or national experiences (Bostancı & Tanyer, 2025; Chatterjee et al., 2024; Ghinoi et al., 2020; Liao et al., 2023; Pusz et al., 2024).

3. Results

3.1. Evolution of networks between QI and CE

The survey conducted allows us to construct three networks, among which the one related to cooperation to generate QI innovations for the development of the CE stands out. The application of the SNA allows us to identify a growth in the size of these networks during the period studied.

Table 3. Levels of interaction and cooperation in 2021 and 2023

Network	Size 2021	Size 2023	Growth
Contacts	186	470	153%
Services	115	240	108%
Innovation	91	639	602%

Source: Prepared internally, 2024.

Figure 2 shows precisely this growth and the transition from a structure characterised by a sort of archipelago of isolated national networks concentrated in a few key organisations to an integrated network through multiple transnational relationships.

Table 3 allows this growth to be quantified in absolute terms, which is notable in the case of the 'Innovation Network', which exceeds 600%. Meanwhile, contact and service provision networks increased by 153% and 106%, respectively. As proposed in H1, Figure 2 and the data in Table 3 show that at the start of the project, interactions and cooperation between CI and CE actors were scarce. In the case of collaboration to develop innovations, it is observed that, in 2021, only a fragmented set of links existed within some countries, led by a few organisations.

Table 4 shows the average centrality and growth of networks in the three main organisational types analysed. QI organisations had greater growth and centrality compared to CE organisations and SIs.

Table 5 shows that growth is higher among organisations that participated in the QI4CE LAC project. Organisations that have

Table 4. Centrality and growth of networks

	Centrality in contact network 2023	Number of new ties in 2023	Centrality in service network 2023	Number of new ties in 2023	Centrality in innovation networks 2023	Number of new ties in 2023
CE organisations	1.6	1.1	0.7	0.4	2.1	1.8
QI organisations	1.8	1.3	0.8	0.5	2.3	2
Support institutions (SIs)	5.7	4.1	2.6	1.5	7.8	6.5

Source: Prepared internally, 2024.

Table 5. Growth in centrality and number of new ties

	Centrality in contact network	Number of new ties	Centrality in service network	Number of new ties	Centrality in innovation network	Number of new ties
Did not participate	1.3	0.7	0.5	0.3	1.6	1.14
Participated	3.4	2.5	1.8	1.1	4.5	3.9
Significance*	0.000	0.000	0.000	0.000	0.000	0

Note: *p-values (ANOVA).

Table 6. Progress of organisations in different types of services

Types of service	New	Adapted	SD	Types of organisations
Establishment of a Standardisation Committee	24	15	61	AB; SB; B
Adoption and development of international standards	27	15	59	AB; SB; B
New scope of accreditation	26	8	66	AB; SB; B; G
Calibration service	14	14	72	M; B; CAB
Reference material	14	6	81	M; B; G
Proficiency test	14	7	79	M; B; G
Training	30	16	54	AB; SB; E; CAB; G; M
Consultancy	22	11	67	AB; B; M; G; SB
Laboratory testing	15	10	75	B; M
Certification	17	11	72	B; M; G; CAB; SB
Inspection	12	8	80	B; CAB
Validation and verification	13	9	78	AB; B; CAB; SB

Source: Own elaboration, 2024.

Note: AB: accreditation body; SB: standard body; CAB: conformity assessment body; M: metrology; B: business; G: government.

participated in project activities triple their average centrality scores compared to other organisations, in all cases and with statistically significant differences (as inferred from the analysis of variance performed).

3.2. Effects on innovations

Although the growth of networks in general and cooperation networks for generating innovations in particular has already been observed, the results obtained by organisations in terms of developing new services for the CE are analysed below.

The results of the survey at the end of the regional project indicate that 68% of the organisations that responded to the survey generated some innovation during the period under review. Table 6 shows the percentage of organisations that made progress in the development of each type of service.

The main innovations were present in the different components of the QI: standardisation, metrology, accreditation, and conformity assessment.

In general, and according to the SNA analysis, there is also a close link between these types of services and the organisational profile. In addition to companies and governments (which participate in most cases), accreditation and standardisation bodies are mainly involved in the establishment of committees and the adoption and development of standards and accreditations; metrology institutions are involved in the development of calibration services, proficiency testing, and laboratories, while CABs are involved in certification and inspections.

For example, in the Quality Infrastructure Fund for the Circular Economy in Latin America and the Caribbean (2022–2024), an initiative that was part of the regional QI4CE project, QI services were developed in the field of standardisation through the adaptation of standards to measure the recyclability potential of packaging,

Table 7. Intensity of participation in events and projects

	Centrality in contact network 2023	Number of new ties in the contact network in 2023	Centrality in service network 2023	Number of new ties in the service network in 2023	Centrality in innovation network 2023	Number of new links in the innovation network in 2023	Heterogeneity in the innovation network (IQV)
Intensity of participation in events	0.482**	0.356**	0.390**	0.295**	0.402**	0.375**	0.417**
Intensity of participation in projects	0.377**	0.413**	0.290**	0.297**	0.441**	0.494**	0.360

Source: Own elaboration, 2024.

Note: Pearson correlation. Significant values (** sig 0.01).

driven by binational initiatives, in this case, the National Institute of Quality of Peru (INACAL) and the Colombian Institute of Technical Standards and Certification (ICONTEC) through Peruvian Technical Standard NTP 222.104:2024, Colombian Technical Standard NTC 6695:2023, and Colombian Technical Standard NTC 6722:2023.

These technical standards were developed in response to the needs of industry in Peru and Colombia and are currently available for application in plastic value chains.

There is sectoral evidence (in plastics, tyres, circular supply chains, ICT services, and urban infrastructure) showing that CE is limited by gaps in standards and certification, which raises the need to innovate in QI services (Coenen et al., 2023; Fehrer et al., 2023; Nguyen et al., 2023; Nogueira et al., 2020; Škare et al., 2024). However, the literature rarely states this need explicitly as ‘innovation in QI services’ but rather presents it as new standards, labels, digital platforms, or governance frameworks.

However, to test the link between the social process developed by promoting cooperation between QI and the CE and its effects in terms of innovation, various tests of association between network metrics, organisational typologies, and these results have been applied. These analyses lead to the following conclusions:

- There is a clear and significant correlation between the intensity of participation in the activities proposed by the project and centrality in the networks (i.e. the size of each organisation's network), particularly in terms of collaboration to develop innovations. Something similar can be said about the increase in the heterogeneity of the composition of these networks, integrating different types of organisations (based on the index of qualitative variation [IQV]). This can be seen in Table 7, where it can also be seen that the growth in the size of the network is linked to this participation.
- On the other hand, the link between the development of innovations by QI for the CE (based on the number of adapted or new types of services) has been analysed, verifying that there is a significant link with the size and growth of each institution's network of contacts (Table 8).

Both findings support H2, demonstrating that the intensity of participation in activities promoted by cooperation projects allows us to predict an increase in the size and heterogeneity of networks, which, in turn, improve the innovative performance of organisations.

Table 8 presents an analysis of the relationship between organisational network metrics and the development of innovations

Table 8. Significance of correlations

	Centrality in contact network 2023	Number of new ties in the contact network in 2023
Development of services for CE by QI organisations	0.389	0.346

Source: Own elaboration, 2024.

Note: Pearson correlation

for the CE during the QI4CE project period. The study constructed multiple networks (contact, service, innovation), wherein each organisation's position – measured through degree centrality, number of new ties, and network heterogeneity – was calculated from structured survey data of QI4CE participants across 3 years. The SNA quantified the number and diversity of organisational connections using centrality metrics and the IQV for network heterogeneity.

To further test the hypothesis that network size and engagement predict innovation outcomes (H2), the authors used Pearson's correlation coefficients to analyse the association between network metrics (e.g. centrality, new ties) and the development of new or adapted services for the CE. Statistically significant correlations (at conventional *p*-value thresholds) indicated that larger, more active networks enhance innovative performance among QI organisations in LAC.

However, as mentioned in H3, the results reveal a particular pattern in the way that position in networks is linked to the capacity to generate innovations. To this end, the organisations (of any type) with the largest contact and innovation networks in each country in the sample analysed were identified. Based on this, we studied whether there was an association between this position of prominence or leadership, their results in terms of innovation, and the composition of their networks, particularly their heterogeneity and degree of internationalisation.

Table 9 shows that there is indeed a link between the results obtained on new services and organisations' capacity to lead coordination processes at the territorial level (in this case, national) and to generate transnational links.

4. Conclusions

The SNA carried out in LAC during the period 2020–2024, which aimed to generate coordination between QI and CE systems in the QI4CE project, has provided valuable evidence on how collaborative networks can strengthen the development of innovations

Table 9. Capacity of leading organisations

	Average centrality in the contact network 2023	Average centrality in the 2023 innovation network	Variety of services developed	Heterogeneity in the innovation network (IQV)	Number of transnational links
National leading organisations	9.25	15.11	7.2	0.78	11.9
Other organisations	3.3	4.7	5	0.53	3.9
Significance*	0.000	0.000	0.029	0.000	0.000

Note: **p*-values (ANOVA).

that contribute to the transition to a CE in LAC. Through systematic mapping and analysis of the relationships between key organisations in the fields of QI and the CE, the study reveals how structured collaboration can catalyse innovation, knowledge sharing, and the development of new services essential for sustainable transformation.

The results of the SNA within this study provide robust evidence in support of all three hypotheses concerning the dynamics of collaboration between quality improvement (QI) and circular economy (CE) systems.

H1, which posits that there are initially limited interactions and cooperation between QI and CE systems in the countries under study, is confirmed by baseline SNA metrics showing fragmented national networks with low density and connectivity in 2021. This reflects the initial inertia of NQS that are oriented towards traditional activities.

H2, which posits that intensive participation in cooperative activities builds larger and more diverse organisational networks, thereby enhancing innovative performance, is strongly validated. This is evidenced by fivefold network growth between 2021 and 2023, increased organisational type heterogeneity (Table 1), and significant positive correlations between participation intensity (e.g. events and projects; Table 7) and innovations in metrology, standardisation, and conformity assessment services (Tables 6 and 8).

H3, which posits that organisations with superior territorial coordination and transnational networking capabilities achieve superior innovation outcomes, is substantiated by centrality measures (Tables 4–5). These measures highlight regional connectors such as QICA as pivotal hubs that forge cross-border ties, overcome homophily-driven closure, and drive service innovations, particularly among capacity-constrained actors.

This evolution from fragmentation to integration highlights the value of SNA in revealing dynamic relational structures, despite limitations such as response rates in data collection. Policymakers and QI organisations should prioritise data-driven investments in regional connectors and inclusive mechanisms to sustain these gains and outperform traditional metrics by capturing long-term network effects beyond the scope of typical project timelines.

As previously noted, there are few studies that address the interaction between QI and CE, so it is hoped that these findings will contribute to increasing such studies and, in the future, enable comparisons between similar processes. However, despite their achievements, the study acknowledges certain limitations. Data collection faced the usual challenges of network research, such as the difficulty of obtaining higher response rates or measuring the relevance of the innovations developed. However, the use of SNA provided a more nuanced and dynamic understanding of the evolution of QI and CE networks, complementing traditional

evaluation methods and enabling the formulation of evidence-based strategies.

The SNA indicators can also be used to identify the necessary cooperation between different groups of stakeholders at an early stage. Measuring the degree of networking at various levels enables us to determine whether QI's services are being accepted by the CE's target user group. This approach is superior to traditional metrics, such as the number of services created and used, because the effects of these tend to become apparent in the long term – often beyond the usual project duration of 3–4 years.

Although the application of SNA in the context of the CE has expanded significantly in recent years (Liao et al., 2023; Khitous et al., 2020), research specifically examining the relationship between QI and CE stakeholder networks remains limited. Comparative studies applying SNA to investigate similar multi-sectoral, transnational collaboration mechanisms, such as the Hubs for Circularity framework documented by Tleuken et al. (2025), would strengthen the theoretical foundation and enable the validation of patterns in network dynamics across different geographical and institutional contexts. A systematic review of SNA studies applied to CE transitions worldwide would advance knowledge and provide methodological benchmarks, as well as identify whether the network evolution patterns observed in the QI4CE project are region-specific or reflect broader CE governance principles applicable across diverse policy environments.

In summary, fostering collaborative networks through structured, data-driven interventions significantly accelerates the transition to a CE. For policymakers, international development organisations, and QI organisations in the region, investing in inclusive and integrated regional collaboration mechanisms is essential to drive sustainable and impactful circular transitions.

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Notes

1. The authors would like to thank PTB for making the project data available and allowing its use for this study. The conclusions of the study do not necessarily reflect the opinion of PTB or its project partners.
2. Calidena is a participatory approach developed and applied by the Physikalisch-Technische Bundesanstalt (PTB) to stimulate quality in value chains. Its toolset can be used in projects that intend to strengthen the user orientation of the national QI and in value chain initiatives that aim at closing quality-related gaps. <https://www.calidena.ptb.de/>.
3. CABUREK (Capacity Building in Technical and Scientific Organisations Using Regional Experiences and Knowledge) is an instrument developed and implemented in cooperation between SIM, OAS, and PTB. This methodology is applied to increase the impact of QI through the promotion of better relationships between the QI and its users. The aim is to develop new QI competences and services that address the needs of users, e.g. circular economy. <https://qica.site/es/qi4ce-lac>, and <https://drive.google.com/file/d/1LbJN4H2tSDS0e5vpfA6ebk3jYte1MtbR/view>.
4. Among national studies, we can cite those by Trajković et al. (2025) or Rab and Brown (2023) in Europe; Rab, Yadav, Jaiswal, et al. (2021) and Aswal (2020) in Asia; or Gutiérrez Ocegueda and Gutiérrez Aceves (2024) and Carvalho Dos Reis and Ludovico de Almeida (2021) in America.

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