Collaboration patterns in Circular Economy Innovation Ecosystems: Evidence from the Horizon Europe programme

Structured abstract

Purpose

The transition to circular economy (CE) models requires robust innovation ecosystems (IEs) that foster collaboration among diverse actors. This paper maps collaboration patterns within Innovation Ecosystems for the Circular Economy (IECEs) to explain how different actors contribute to CE development and why structural bottlenecks emerge.

Design/methodology/approach

We conduct a multilevel, directed network analysis of 276 Horizon Europe projects involving 2,364 organisations across 31 countries, examining macro (country) and micro (organisation/type-of-agent) structures. We compute centrality, modularity and density, and assess dynamic robustness via targeted node-removal simulations.

Findings

Countries that are advanced in CE are not always the ones at the centre of collaboration. Coordination tends to sit with a small group of countries. At the organisational level, firms mainly secure and use funding and deliver projects, while universities and research centres connect partners and often lead coordination. The public bodies are less well integrated. The network holds together, but it leans heavily on a few highly connected players and leaves smaller clusters at the edges. If the key players step back, collaboration and the spread of CE solutions could slow.

Practical implications

The findings provide actionable insights for policymakers and funding bodies to refine collaboration frameworks, ensuring better alignment between innovation efforts and CE policy objectives.

Social implications

Strengthening collaboration within IECEs can accelerate the transition to sustainable economic models by fostering innovation-driven solutions to resource efficiency and waste reduction. Enhancing participation from diverse stakeholders, including public institutions, can contribute to more inclusive and effective CE policies.

Originality/value

We foreground the misalignment between actors' transition mandates and their network positions and introduce role–centrality fit as a governance lens for assessing and improving IECE performance across macro- and micro-levels.

Keywords

Innovation Ecosystems; Circular Economy; Collaboration; Horizon Europe; Networks

1. Introduction

Circular Economy (CE) proposes a closed-loop system in which design, material management and zero-waste policies are aligned to decouple value creation from resource depletion (Jakobsen et al., 2021). CE principles prioritize redesigning products to reduce material usage and promote reuse, remanufacturing, or recycling rather than disposal after single use. Recent years have seen growing support for CE among scholars (Blomsma & Brennan, 2017; Linder & Williander, 2017; López-Manuel et al., 2020; Quatraro & Ricci, 2023; Witjes & Lozano, 2016), policymakers (EU, 2020; Ellen MacArthur Foundation, 2019), universities (Del Vecchio et al., 2020; Prieto-Sandoval et al., 2019), and firms (Kennedy & Linnenluecke, 2022; Triguero et al., 2022). Yet delivering CE in practice requires more than technological fixes: it asks for integrated innovation along supply chains and across institutional boundaries.

Since such systemic innovation stretches the capabilities of any single organisation, collaboration becomes indispensable (Alka et al., 2024; Schultz & Reinhardt, 2022). Research emphasises that redesigning products, processes and consumption practices for circularity demands shared resources, complementary knowledge and coordinated standards (Korhonen et al., 2018; Dorrego-Viera et al., 2025). Innovation ecosystems (IEs) offer a governance model that orchestrates these multilateral relationships, mitigating the resource constraints that isolated actors face and accelerating knowledge sharing enabling faster problem-solving, enhancing creativity and accelerating the pace of technological advancement through synergies (Ferrer-Serrano et al., 2024; Lozano et al., 2021; Ferrer-Serrano & Salesa, 2025).

Despite their relevance, there has been no previous attempt to understand their current state and implications, particularly in terms of their network structure. Specifically, research has not yet assessed how countries, organisations and agent types are positioned within an Innovation Ecosystem for the Circular Economy (IECE), nor whether current structures favour or hinder knowledge diffusion. Clarifying these patterns is essential for designing incentives, monitoring progress and theorising how network form shapes sustainability outcomes. To address this gap, we ask: what collaboration patterns characterise Europe's IECE, and how do they relate to each actor's contribution to CE goals? Our objective is therefore to map and interpret the multilevel structure of an IECE, moving beyond descriptive listings of participants toward a relational explanation of who negotiate, who benefits and where fragmentation may arise.

To achieve this, we examine the Horizon Europe programme (2021-2027), the largest European IECE to date, with a budget of €95.5 billion.[1] Its objectives include fighting climate

[1] More information: https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe_en

change, achieving the Sustainable Development Goals, and boosting EU competitiveness and growth. The programme fosters these goals by (i) facilitating collaboration among diverse economic agents across Europe and (ii) strengthening the role of research and innovation in shaping EU policies. These characteristics make it an ideal case to study collaboration patterns between agents with diverse economic profiles (public vs. private), skills and knowledge (e.g., research institutions vs. companies), and geographies, contributing to the European transition to a CE model.

Our dataset includes 276 projects—2,364 organizations from 31 countries—funded through Horizon Europe calls. We employ structural network analysis to map the collaboration patterns at both the organizational and country levels. The analysis captures the geographic distribution, skills, and knowledge diversity of participants and evaluates how these relationships facilitate knowledge transfer critical to achieving a CE model.

Our findings are threefold. At the country level, the network exhibits a medium-to-high density, particularly in its inner part, making fragmentation of the network unlikely. While this somewhat reflects the strength of the European IECE, a comparison between countries' network position and their CE performance suggests that those countries leading in the implementation of the CE model do not occupy a central role in the IECE. We posit that these patterns may have to do with differences in how countries react to incentives for participating in innovation collaboration networks: Northern countries—leading actors in the deployment of CE—might respond better to market-driven incentives than to institutionally-driven ones (such as Horizon Europe), which require a coordinating third party.

Second, at the organizational level, we also show that the European IECE is cohesive, but with two important nuances. First, while suggesting that the network is unlikely to become fragmented at the center, the outer region of the network is organized in clusters that remain partially disconnected from its densest part. Second, while private companies, research centres, and universities are spread throughout the European IECE, public institutions are mainly located in the outer part. This suggests that the latter are somewhat disconnected from the European IECE, something that may be slowing the development and adoption of the CE.

Finally, considering the different types of agents in the European IECE, we show that private companies occupy a central role in the network when it comes to receiving funding and executing innovations. However, they are not as involved in the coordination of projects as research centers and universities, which prioritize knowledge-intensive tasks. This reveals a specialization of roles among the agents within the network, with firms being motivated to engage in collaborations with stable knowledge-intensive partners—particularly as the stringency of environmental regulations increase.

This paper is structured as follows: Section 2 presents the theoretical background. The first subsection delves into the existing literature on IE, the connection between CE and collaborative networks, and its conceptual implications. Section 3 describes the sample and methods employed, and Section 4 presents the results. Finally, Section 5 finishes with a discussion of the results obtained and the exposition of the main conclusions, implications, limitations, and suggestions for future research.

2. Research Background

Addressing today's innovation and sustainability challenges requires new forms of collaboration that go beyond the boundaries of individual organisations. IEs have gained prominence as frameworks that enable the exchange of knowledge, resources, and capabilities among diverse actors. These ecosystems foster value creation through inter-organisational collaboration, supporting firms in navigating complex, dynamic environments. Section 2.1 explores the structure and strategic relevance of IEs in driving innovation performance.

Simultaneously, the transition to CE calls for systemic changes in how value is created and delivered, demanding collaboration across sectors and disciplines. IEs can play a pivotal role in supporting this transition by enabling shared learning, co-development of circular business models, and alignment with supportive policy and funding environments. Section 2.2 examines how IEs contribute to advancing CE practices through mechanisms such as cross-industry collaboration, technology deployment, and regulatory engagement.

By bringing these two perspectives together, this section lays the groundwork for understanding how IEs can simultaneously enhance innovation and support the adoption of circular principles—an essential foundation for the study's analytical focus.

2.1. Innovation Ecosystems for value creation

An expanding body of scholarly work highlights the transformative potential of knowledge acquired from external sources (Bolatan et al., 2022). Not only can externally sourced knowledge ignite important organisational transformations, but also inter-organisational collaboration is a powerful catalyst for technological and economic improvements at the societal level (Baglieri et al., 2018; Coccia, 2019; Ferrer-Serrano et al., 2022; Inkpen & Tsang, 2005; Kotabe et al., 2003; Nepelski & Piroli, 2018).

With the backdrop of increasingly complex organisational environments, the attention of management researchers has gravitated toward IE (Ritala, 2023). On the one hand, globalisation and digitalisation have ushered new participants into the competitive landscape (He & He, 2025). On the other hand, they have blurred the once-distinct boundaries within industries and intensified competition. Therefore, engaging in collaborations with new participants within the IE is imperative, as it provides greater access to strategic resources and partnerships that enrich the collective knowledge pool. Research has shown that resource-sharing relationships within IEs are reservoirs of valuable information and technologies (Dhanaraj & Parkhe, 2006; Swan et al., 1999).

Consequently, IE members are exposed to acquiring and assimilating diverse resource sets, including valuable technologies. As a precursor to driving innovation performance, the exchange of resources emerges through interactions and the spill-over effects within these collaborative relationships (Farinha et al., 2016). Also importantly, evidence demonstrates that individuals, organisations, or countries—depending on the level of analysis—significantly enhance their innovative capabilities by leveraging the skills and resources of others through these resource exchange networks (Inkpen and Tsang, 2005).

Examining the configuration of IE through structural network analyses provides a means to model the intricate web of relationships and interactions among economic agents. First, it contributes to a deeper comprehension of the behaviours exhibited within an IE. Second, it also facilitates the identification of pivotal actors and the evaluation of the overall IE performance. Past studies have concluded that the positions held by actors, as shaped by the nature of their relationships, interactions, and linkages, are as influential as the geographic spaces they occupy (Ferrer-Serrano et al., 2021; Huggins et al., 2012; Tsai, 2001; Tsouri & Pagoretti, 2021). Consequently, analyses that neglect to consider the interactions among agents within a given IE remain incomplete and can potentially yield misleading conclusions concerning collaborative patterns.

2.2. IE as enablers of the circular transition

Transitioning to CE requires a new economic model based on strategies for closing, slowing, or narrowing resource flows (Barreiro-Gen & Lozano, 2020; Herrero-Luna et al., 2022; Salesa et al., 2023). However, this entails many challenges, and organisations struggle to change their existing linear business models to circular ones. In this sense, IEs have a relevant role, as they can promote sustainable innovations through collaboration (Suchek et al., 2021). This inter-organisational collaboration creates a fertile ground for developing innovative technologies, processes, and business models that support the CE (Talmar et al., 2020). To get a deeper understanding of the nexus between IE and CE, this section illustrates the main mechanisms of developing CE through IEs.

Cross-industry collaboration

Cross-industry collaboration is essential for the transition to a CE. It can accelerate innovation, improve efficiency, reduce costs, and increase customer value (Köhler et al., 2022; Luhtra et al., 2022). CE initiatives are developed through high-tech innovation; sometimes, there are some requirements and processes that different practitioners and experts should review (Scarpellini et al., 2020; Radu & Lux, 2024). Therefore, collaboration among multiple agents becomes crucial to developing innovations (Aouinaït, 2021; Kuhlmann et al., 2023). IE provide a platform to exchange resources and capabilities on interdisciplinary solutions that align with CE principles (Arranz et al., 2019). Also, knowledge sharing among different ecosystem actors can help reduce individual limitations, such as insufficient training or lack of technologies (Aouinaït, 2021).

For instance, companies in the textile industry work together to develop new recycling technologies and create new markets for recycled materials (Dano et al., 2020). In the electronics industry, companies take advantage of collaboration to design more accessible products to disassemble and recycle and develop new recycling technologies for critical materials such as rare-earth metals (Pollard et al., 2023). Additionally, food industry companies collaborate to reduce food waste and develop new products made from food waste (Cicullo et al., 2021; Ranjbari et al., 2024; Teigiserova et al., 2020). Cross-industry collaboration is also fundamental, for it can help identify and eliminate supply chain inefficiencies (Kuhlmann et al., 2023; Tsolakis et al., 2023).

Circular Business Models

The transition from linear to closed-loop production and consumption models requires new business models. These new business models, recently known as Circular Business Models, demand production and consumption to fit today's societal and environmental challenges. Due to the interconnection capacity among its agents, IEs offer opportunities to explore and implement new Circular Business Models that deliver fundamental changes to how products and services are exchanged.

In particular, we posit that IEs are particularly relevant for developing and implementing two different Circular Business Models. To begin with, there is the *Product-as-a-service* model, where customers pay for access to a product's services rather than owning the product itself. These models reduce the number of goods produced and consumed, making it easier for companies to take back and recycle products at the end of their useful life (Barreiro-Gen & Lozano, 2020; Lozano et al., 2021). Here, IEs can help firms retain product ownership and provide it to customers as a service (Korhonen et al., 2018; Lieder et al., 2017). Second, IEs can provide access to various sources of funding (considering they are usually startups), including venture capital, angel investors, and government grants. Third, IEs are typically rich in technology resources and infrastructures, allowing new firms to leverage these resources to develop and deploy their business model offerings efficiently and at a lower cost. Finally, they can facilitate interactions with regulatory bodies and policymakers, helping navigate the legal and compliance challenges associated with their business model.

Additionally, IEs are relevant for developing platforms that allow people to share products and services (Salesa et al., 2023). These platforms can reduce the need to purchase new products and extend the lifespan of the existing ones. Here, IE can drive the development of technologies that enable efficient recycling, remanufacturing, and repurposing of materials, contributing to the circularity of resources (Despeisse et al., 2017; Diaz-Lopez et al., 2019).

Policy and regulatory support

IEs are pivotal in shaping policy discussions and advocating for regulatory support that encourages the widespread adoption of CE practices (Fuller et al., 2022; Stubbs, 2008). For instance, IEs are instrumental in proposing policies that promote innovation, drive sustainable practices, and establish standards for environmentally friendly products and processes. Also, through specific R&D policies, governments can set clear and ambitious targets to transition to a CE. Setting these targets is essential to signal firms and investors that CE is a priority and create a sense of urgency and momentum.

A critical tool IEs employ to enhance collaboration and accelerate CE adoption is creating a supportive regulatory environment. This involves a comprehensive review and update of existing regulations and the development of new ones (Alcayaga et al., 2019). These regulations are designed to facilitate the adoption of CE practices, ensuring they are practical, realistic, and conducive to Circular Business Models (García-Granero et al., 2025). Moreover, IEs actively promote collaboration and partnerships between businesses, academia, and other stakeholders in the CE (Bocken et al., 2017). By bringing these entities together, IEs support accelerating innovation and scaling up CE solutions. This collaborative approach informs policymakers and empowers them to create more effective, evidence-based regulatory frameworks that can drive the transition to a CE.

Education, investment and funding

IE often involve educational institutions and research organisations. These institutions can play a crucial role in raising awareness about the importance of the CE and training the next generation of professionals equipped with the knowledge and skills needed to drive sustainable innovation (Del Vecchio, 2020; Tukker et al., 2004;). Several initiatives like the Ellen MacArthur Foundation, Circular Economy Leadership Fund, Circular Economy Startup Accelerator and Circular Economy Innovation Hub provide educational resources, including online courses, toolkits, and case studies oriented to every educational level (Blomsma & Brennan, 2017; EMAF, 2020).

In addition, funding is an essential aspect of enhancing the development of CE due to the high cost of tech innovations required. Investors and venture capitalists within IEs may recognise the potential for growth and profitability in CE-focused firms (Stahel, 2016). These can lead to increased investment in projects that align with CE principles. Currently, it is noteworthy that some European projects (EU, 2020; Mhatre et al., 2021; Thakur & Wilson, 2023) were launched with the primary mission of advancing the CE through the collaboration of various members and branches of knowledge and partnerships with professionals (Morseletto, 2020). This is due to both the synergy of these actors and the collective capacity they harness, which leads to the development of ideas that might otherwise be unattainable. At the same time, governments can provide financial incentives to agents that invest in CE innovation (Mhatre et al., 2021) through grants, loans, tax breaks, and other forms of support.

Scaling solutions

Successful CE solutions need to scale to have a significant impact. IEs provide the necessary resources, mentorship, and connections for these solutions to grow and expand their reach (Jacobides et al., 2018; García-Granero et al., 2025). Circularity Decks, "a card deck-based tool that can help firms to analyse, ideate and develop the circularity potential of their IE" (Konietzko, 2020), takes a similar idea to brainstorming meetings where designers, entrepreneurs and managers with specific knowledge of CE share their needs and identify how to satisfy them through new thoughts or actions (Konietzko, 2020). Thanks to this approach, it is possible to state the requirements of new technological development (Han et al., 2023), and all parties can mention the limitations that may arise to address them and evaluate aspects that might not otherwise be taken into account.

3. Methodology

3.1. Sample description

The data collection was conducted based on information provided by Horizon Europe's strategy [2]. Horizon Europe (2021-2027) has its roots in the Horizon 2020 strategy. It is the most extensive research and innovation strategy in funding to date, with a budget increase of nearly 19 per cent compared to its predecessor, amounting to 95.5 billion euros. While Horizon Europe is relatively new, previous studies analysing resource flows have demonstrated the adequate research potential of Horizon 2020 (Ferrer-Serrano et al., 2021) in understanding directional relationships and IE configurations.

[2] More information:
https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe_en

To date[3], Horizon Europe has financed 5,765 projects. Given that our research objective focuses on projects that enable some of the transition to a CE, we screened the abstracts of the projects based on the following keywords: "circular", "CE", and "closed-loop". We selected those keywords as previous literature has identified and used them indistinctly for referring to CE (Mishra et al., 2018; Salesa et al., 2022). 308 projects fitted the filtering process. After that, we double-checked all the abstracts following intra-observer screening criteria to ensure they were projects effectively driving the transition to CE somehow. From this step, we excluded 42 projects as they referred to CE as a possible consequence and not a relevant research objective.

For our research purposes and considering European circularity data, we selected only those projects coordinated by countries listed in Appendix I (thus excluding external countries) and considered participation from organisations in those countries. This screening resulted in a final sample[4] of 3,458 dyads, 276 financed projects (totalling 1,351,437,993.69 euros), and the involvement of 2,364 organisations from 31 different countries[5].

After identifying the final sample of relevant Horizon Europe projects, we proceeded to structure the data for network analysis by creating three distinct datasets, each corresponding to a specific level of analysis: country, agent, and organisation. For each level, we constructed two key matrixes: a nodes table, which defines the individual actors within the network, and an edges table, which captures the connections between these actors, including information on the strength or weight of each link. The nodes matrix allowed us to formally identify each country, agent, or organisation as a network node within the analytical software, while the edges matrix defined the dyadic relationships—such as co-participation in a project—that connect these nodes. Note that the origin of the relationship corresponds to the coordinator of the project, while the destiny corresponds to the executors or participants involved.

This structure enabled us to capture the multi-layered nature of collaboration within the CE field as promoted by Horizon Europe. The resulting matrices were then imported into Gephi, an open-source platform for network visualization and analysis. Gephi was used both to generate graphical representations of the networks and to compute key metrics such as centrality, density, and modularity. The entire process—from initial data collection to final network analysis—is summarized in Figure 1, which illustrates the sequential steps and the corresponding outputs at each stage.

[3] Data search was conducted on 2nd July 2023.
[4] Data will be available under request.
[5] As elaborated in the main text of the manuscript, we excluded specific country participations from outside our sample (Appendix I) in projects considered for this research. This accounts for the disparities in economic contribution and the number of participations between the total sample and the screened sample employed in this study.

Insert Figure 1 around here

3.2. Network analysis: indicators and attributes

Network analysis is particularly well-suited for examining the configuration of IEs because it models collaboration not as isolated dyads, but as interdependent, multilateral structures where each actor's position and connections matter. Given that IECEs are designed to foster knowledge flows, resource exchange, and coordination across diverse stakeholders, a relational approach is essential. Unlike traditional regression-based methods, which assume independent observations, network analysis treats organizations (or countries) as nodes in a graph and models their ties—such as project collaborations—as edges. This approach captures key dimensions of agent behaviour such as centrality (how prominent or influential an actor is in the ecosystem); brokerage (the capacity of actors to bridge disconnected parts of the network); modularity (the extent to which collaboration is fragmented or cohesive); or role specialization (how different types of actor's function in distinct parts of the network).

These aspects directly link to our research questions (see page 2), which focus on actor prominence, role differentiation, and structural integration. Additionally, Horizon Europe itself is organized as a multi-actor, multi-country ecosystem where outcomes depend not just on who participates but also on how they are interconnected. Network analysis is therefore a conceptually aligned and empirically precise method for investigating the collaboration patterns that underpin CE innovation.

In particular, this study focuses on directed graphs since we assume that TT flows are directional. In other words, a dyad will always have an origin and a destination, and the flow will not occur in the opposite direction. For our analysis, we consider the origin of the relationship to be the country that plays the coordination role in the project. This country coordinates and allocates technology resources among the other participating countries, while the destination refers to the remaining countries involved in the project who act as executors. These executor countries adopt and absorb knowledge or technology resources to execute the coordinator's guidelines.

To characterise the network, we employ the concept of *modularity* and *density* (Newman, 2006). Modularity is a measure of the network structure or graph that quantifies the strength of division into modules (also known as clusters or communities). Modularity indicates whether the network's coherence is sensitive to minor changes, such as removing a single node or dividing the network into two or more separate parts. Networks with high modularity exhibit dense connections between nodes within modules but sparse connections between nodes in different modules. While modularity provides insight into the static structure of the network, it does not capture how the system behaves under perturbation. High modularity networks are often less robust to node removal, especially when critical nodes (e.g., hubs or bridges) are removed, as their communities are more weakly connected. Therefore, in addition to topological characterization, we assess the dynamic robustness of the IECE through simulated node removal. Density measures how many ties between actors exist compared to how many ties between actors are possible. As such, the density of an undirected graph is quite simply calculated as "total edges/total possible edges". The density value ranges from 0 to 1, with the lower limit corresponding to networks with no relationships and the upper limit representing all possible relationships.

In addition, various metrics help us understand behaviours within a network. Centrality metrics are essential for highlighting the significance of an entity's position in the network. We employ four different metrics to fulfil this purpose.

Degree centrality (indegree/outdegree) (Freeman, 1977) measures the number of links a node has and indicates how well-connected an institution is regarding direct links. While it accurately represents an institution's connectivity level, it does not reflect its position within the network. The theoretical representation of degree centrality is as follows:

$$DC^{v_i} = \frac{d(v_i)}{|V| - 1}$$

Where *d(vi)* represents the degree of centrality of the node *vi* in the network, indegree centrality indicates the number of edges directed into a vertex in a directed graph. In contrast, outdegree centrality represents the number of edges directed out of a vertex in a directed graph. The sum of both indegree and outdegree centrality values equals the degree centrality.

Betweenness centrality (Freeman, 1977) quantifies the frequency with which a particular node appears on the shortest path between any two nodes in the network. This metric is employed to measure the significance of an agent in the network and explore the influence these agents may have on initiating new relationships through potential mediation. Let *np (vj, vk)* denote the number of paths between $vj \in V$ and $vk \in V$. The centrality of the node vi, in terms of connecting vj and vk, is obtained as a ratio. Formally:

$$BC^{v_i} = \sum_{v_j \neq v_k \neq v_i} \frac{\frac{np_{v_i}(v_j, v_k)}{np(v_j, v_k)}}{\frac{1}{2}(|V|-1)(|V|-2)}$$

Closeness centrality (Beauchamp, 1965) measures the proximity of a node to other nodes in the network. It can be interpreted as the ability of an agent to connect with other agents. Closeness centrality emphasises the distance between one actor and others in the network by considering the geodesic distance of each actor from all others. Mathematically, it is represented as follows:

$$CC^{v_i} = \frac{|V|-1}{\sum_{v_i \neq v_j} sp(v_i, v_i)}$$

where *sp* (v_i, v_j) is the number of connections on the shortest path between the v_i and v_j node.

Eigenvector centrality (Bonacich, 1987) quantifies the importance of a node in the network, considering its neighbours' centrality. It is based on the idea that the centrality of a node depends on how central its neighbouring nodes are. Eigenvector centrality provides a more sophisticated measure than degree centrality by considering that not all connections are equally significant. Let *EC (G)* denote the centrality of a vector associated with a network *G.* The key concept is that the centrality of a node is proportional to the sum of the centrality values of its neighbours. Its representation is as follows:

$$\lambda \cdot EC^{v_i}(G) = \sum_{v_j} g_{ij} EC^{v_j}(G)$$

in which g_{ij} takes the value 1 if $(v_i, v_j) \in E$ and 0 otherwise and k is a proportional factor.

4. Results

Three different IECE scenarios have been studied. In the first scenario (Section 4.1), we present the country-level European network focusing on CE. The second scenario (Section 4.2) depicts the network at the type of agent's level, highlighting the collaboration between different roles of agents and enabling us to compare the roles of agents (coordinator vs participative). Lastly, the third scenario (Section 4.3) focuses on an organisational level, allowing us to visualise the most desegregated level of analysis. We have chosen these scenarios because they incorporate different visual representations, thereby providing complementary results that allow the understanding of the complete picture of the major innovation strategy for CE to date.

4.1. Country-level analysis

The network depicted in Figure 2 exhibits a medium-to-high density[6], particularly in its inner part, making fragmentation of the network an unlikely possibility. This level of analysis is complemented with a composite index performed and presented in Appendix II using data from the European Commission.

Insert Figure 2 around here

The most central are countries (Germany, Spain, Italy, France, Belgium and Greece) that do not stand out in terms of the level of CE (except Belgium and Germany) since they correspond to countries with intermediate results in terms of CE development (see Appendix II). Nevertheless, these six countries try to adopt a strategic and central position in the network. In contrast, most Nordic countries (such as Denmark, Austria and the Netherlands, with higher levels of CE) and some Western countries do not stand out in the network. Finally, on the outside, some countries are either small in size (e.g., Luxembourg, with relatively high CE potential) or have a lower innovation capacity (Lithuania, Romania, Latvia or Slovakia, among others). Most of the members of this last network set are from Eastern European countries.

Figure 3 represents the same network but with a different layout. In this case, the modularity coefficient was calculated to cluster the IECE. This algorithm allows the identification of different communities of collaboration. Based on the modularity indicator, we have identified four collaborative communities distinguished by different colours. It is important to note that a community within a network signifies a cluster of nodes with solid internal connections and relatively weaker connections to external nodes. In addition, the Outdegree Centrality indicator has been included as an attribute of the network (node size) to contemplate, at a glance, the capacity of countries' CE resources exportation in the ecosystem.

Insert Figure 3 around here

All the centrality and contribution results can be found in Table 1. Following the findings from previous graphs, the leading countries in terms of CE, namely the Netherlands, Belgium, Denmark, Ireland, Austria and Iceland, are not situated in the most central positions within the

[6] Density coefficient 0.424 out of 1. This means that half of network is highly dense, while the rest of the network is quite fragile and become fragmented.

network (except for Belgium and Denmark). These countries are mainly distributed across Communities 0 and 3. Conversely, on the one hand, Community 1 groups Spain and the Netherlands; on the other hand, Community 2, with France, Italy, and Greece, concentrates on countries that represent the highest centrality of the IECE.

Insert Table I around here

Through the analysis of the particular indicators of the network, it is also noticed that although some countries stand out in almost all attributes, some particularities need to be considered. As it was previously shown, Belgium, Denmark, Greece, Spain, France and Italy concentrated the best positions at the IECE (representing 62% of the total contribution). First, Belgium, Spain and France especially stand out in their Indegree centrality, meaning that their role as coordinators is not as relevant as their executor role, although it is above average. In other words, these countries import, in relative terms, more resources and capabilities than what they export. In contrast, Denmark, Greece and Italy, operate the other way around. They exhibit high Outdegree centrality, which refers to their importance as coordinators at the IECE. The Closeness and Betweenness centrality attributes support these findings, showing the importance of these countries on the IECE. In these attributes, Austria, the Netherlands, Norway and Finland also join the group with the highest coefficients, explaining their potential to establish new relationships due to their proximity to the most relevant nodes of the IECE.

4.2. Agent level analysis

In the second scenario, the organisations have been classified into five categories: Private Companies (PRC), Research Centres (REC), Universities (HES), Public Administrations (PUB) and Others (OTH), to deepen the understanding of the functions and roles of the IECE agents. Subsequently, the IECE network has been built among the agents.

Figure 4 represents the network graphically[7]. It highlights the role of private companies in the ecosystem (both in terms of funds raised and their Eigenvector centrality), while public administrations go unnoticed. However, suppose attention is paid to the intensity and direction of the arrows. In that case, the high values in the eigenvector centrality are due to the quality of their connections. The two prominent arrows are directed to private companies, meaning they do not have a coordinating role in the projects coordinated by the Universities and Research Centres.

[7] Density coefficient 1 out of 1.

The arrows that emerge from Private companies do not stand out in the graph, allowing us to understand that their Outdegree centrality is barely low.

Insert Figure 4 around here

To clarify the roles of the types of agents involved in the IECE, two parallel networks have been projected whose difference lies in the colour of the nodes (see Figure 5). The network on the left represents the network of participating agents (follower role in the development of CE research). In contrast, the network on the right represents the agents coordinating the projects (leadership role).

This representation helps to understand the role of the type of organisations in the network. Although private companies are the economic agents that attract the most significant budget from the initiative, their role seems limited to being executors. At the same time, the research centres and universities are leading the IECE. This reinforces the theoretical argument of the role of the types of organisations. While universities are economic agents that generate fundamental knowledge, companies generally drive the process of commercialisation.

Insert Figure 5 around here

4.3. Organisational level analysis

This section reinforces the findings of the previous section. For the construction of this network[8], the dyads between individual organisations have been considered. We performed different visualisations of the same network by using different characterisations to understand its structure deeply. As a result, three different figures can be found in this section.

First, Figure 6 represents the network under the algorithm *OpenOrd*. It is one of the few force-directed layout algorithms that can scale to over 1 million nodes, making it ideal for large graphs. This algorithm aims to distinguish clusters better. On the left side of the picture, the hole graph lets us see the complexity of the IECE structure. In the upper-right side, a detail of the clusters and the connection power of specific organisations unifying clusters from the outer regions and the centre of the network (for example, *Deutsches Zentrum Für Luft - und Raumfahrt e.V.* (DLR), connecting the cluster of *Alia Servizi Ambientali S.P.A.* (ALSER) and *Ministero delle Imprese e*

[8] Density coefficient 0.147 out of 1.

del Made in Italy (MINDEI) with more centralised clusters like *Fundación Cartif* (CARTIF). The low-right side represents a detailed picture from the centre of the network, the densest part of it. It concentrates on the most centralised organisations (node's colour) and where most of the funding is located (node's side).

Insert Figure 6 around here

Table 2 shows the top-ranked organisations according to the centrality indicators. For this table, the Top five organisations for each of the attributes were selected. This selection process resulted in just eight organisations concentrating on the highest centrality metrics of the IECE and the 7% of the total budget distributed. This IECE sample selection reinforces the findings of the previous sections. It can be seen as the most outstanding countries and agents in the network.

Insert Table II around here

Intending to explore the network's modularity, we depicted the graph in Figure 7. This graph adopts a different structure as performed with the *Yifan Hu* layout. This algorithm combines a force-directed model with a graph coarsening technique (multilevel algorithm) to reduce the complexity. It is a high-speed algorithm and works well with large datasets. Due to its strength of repulse and attraction, it can locate the most centralised organisations in the network's centre while placing the unconnected nodes on an external ring.

Insert Figure 7 around here

In addition, it calculated the network's modularity and coloured it according to its communities. As it can be seen, although there is a deep mesh in the centre, as the partnerships are distributed outward, the segmentation is higher, and so, the communities are conformed. This may be due to the high specialisation of the organisations building the network. Nevertheless, its possible fragmentation does not seem easy, at least at the centre of the graph, where the most centralised organisations are located. This means that network fragmentation could occur in communities where its connectivity to the centre depends on few links.

Finally, to understand the economic agents' pattern role, we performed Figure 8. This figure shows the same network coloured by the different economic agents on which this paper focuses. Interestingly, the agent's role and behaviour in the complete network can be identified. In line with our previous findings, Private Companies, in contrast to Research Centres, are located in the outer part of the network, revealing their low centrality capacity. Instead, Research Centres take the most advantageous positions in the network, showing their coordination capacity and connectivity power. Universities are also highly present in the network, while Public Institutions occupy discrete positions in the external part of the IECE.

Insert Figure 8 around here

----

5. Discussion

This section discusses the Horizon Europe collaboration network through the lens of CE transition theory and translates the resulting insights into concrete avenues for policy, management, and future scholarship. The argument unfolds in two parts. The first distils the empirical regularities into a unifying conceptual insight—the structural mis-alignment paradox—while the second elaborates this paradox's practical and scholarly significance, offering a roadmap for corrective action and outlining the study’s limitations.

5.1. Structural mis-alignment paradox

Our multilevel analysis reveals three interrelated structural patterns that, when taken together, expose a paradox at the heart of Europe’s IECE. This paradox concerns the misalignment between actors' formal mandates and their actual structural positions within the network—raising questions about coordination efficiency and institutional fit in mission-oriented innovation systems.

First, we observe a notable decoupling between countries’ CE maturity and their centrality in coordinating Horizon Europe projects. While nations such as Sweden, Finland, and the Netherlands are widely recognized as CE frontrunners (Circle Economy, 2023; Calisto Friant et al., 2020), they do not occupy leading coordination roles in the IECE network. Instead, countries such as Spain, Italy, France, Belgium, and Greece form the coordination core. This misalignment suggests that a country’s historical integration into EU funding architectures—particularly its administrative absorptive capacity and project management experience—plays a greater role in shaping coordination centrality than its performance in CE policy implementation. This finding resonates with extant work on EU research frameworks, which underscores the importance of institutional path dependency and familiarity with Brussels-style funding instruments as drivers of participation and influence (Lepori et al., 2007).

A further dimension of structural vulnerability emerges from our robustness simulations presented in Figure 9. These analyses show that while the IECE exhibits core cohesion under random or moderate perturbations, it becomes significantly fragmented when highly central nodes are systematically removed. Specifically, the removal of countries with more than 40-degree centrality points—representing only 18.2% of the sample—disrupts the network's coordination core. At the organizational level, just 5.2% of nodes exceed 10-degree centrality points, yet their removal similarly fractures the collaboration landscape. These results underscore a critical fragility: the network's resilience is disproportionately dependent on a small group of highly connected actors, predominantly located in Western and Southern Europe. This confirms findings in network science literature that emphasize the vulnerability of scale-free or core-periphery networks to targeted node removal (Barabási & Albert, 1999; Newman, 2003). From a mission-oriented perspective, such fragility challenges the long-term sustainability of the IECE and highlights the importance of cultivating redundancy and distributed capacity. Expanding the involvement of peripheral actors—especially from underrepresented countries and public institutions—can mitigate these systemic risks and increase the resilience of Europe's circular innovation system under political, financial, or organizational shocks. While our analysis primarily frames peripheral positioning as a limitation for coordination and integration, it is important to recognise that peripherality can also offer strategic advantages. Peripheral actors often enjoy greater autonomy, enabling them to pursue niche specialisations or experimental approaches that might be harder to sustain under the scrutiny and path dependencies of the core (Glückler, Shearmur, & Martinus, 2022). Their weaker embeddedness in the network's dominant structures may reduce exposure to institutional inertia and open opportunities to connect with external networks, acting as gateways for novel ideas, resources, and practices (Granovetter, 1983). In this way, peripherality can complement centrality by introducing diversity, flexibility, and fresh perspectives into the innovation ecosystem—qualities that can enhance resilience and adaptability in the long term (Snorek et al., 2022).

Insert Figure 9 around here

Second, our data point to a structural division of labour across organisational types. Universities and public research centres initiate the majority of collaborative ties, even though they represent only a third of the participants. In contrast, private firms—while securing the largest share of project funding—are less central in fostering inter-organisational connectivity. This asymmetry mirrors classical models of mission-oriented innovation systems (Mazzucato, 2018), where public research actors serve as coordinators of collective problem-solving and frame the cognitive architecture of emerging technologies, while firms provide downstream capabilities and commercialization pathways (Weber & Rohracher, 2012). By providing a network-level quantification across 2,364 organizations, our study scales up prior case-based insights (e.g., Kuhlmann & Rip, 2018) and provides empirical grounding for theories of functional differentiation in sustainability transitions (Schot & Steinmueller, 2018).

Third, public authorities are structurally peripheral. Despite comprising 12% of all participants, they account for less than 4% of bridging ties and are predominantly located in the lowest quartile of centrality scores. This peripheral positioning suggests that regulatory and policymaking bodies are brought into consortia only at late stages, limiting their influence on the design and direction of innovations. Prior research has noted similar temporal misalignments in sustainability governance, where regulatory institutions tend to lag behind technological experimentation (Borrás & Edquist, 2013; Sabel & Zeitlin, 2012). Such lags can hinder feedback loops between innovation and institutional adaptation, especially when legal or policy frameworks are needed to scale promising pilots.

Together, these three patterns constitute what we term a structural misalignment paradox: the actors formally tasked with steering socio-technical transitions—national public authorities—are marginalized within the collaboration network, while actors with limited regulatory power—researchers and private firms—occupy central positions. This misalignment poses a coordination challenge: the conversion of experimental knowledge into systemic impact is slowed when those empowered to codify and disseminate solutions are poorly positioned to broker cross-sectoral learning.

Conceptually, we propose a shift from conventional metrics of ecosystem performance—such as density or diversity—to the idea of role–centrality fit: the extent to which an actor's societal function (e.g., regulation, experimentation, scaling) aligns with its structural position within the network. A poor fit may reduce the efficacy of mission-oriented programs by weakening critical feedback loops and creating coordination gaps. Incorporating this perspective complements recent calls in transition studies and ecosystem research to move beyond actor presence and toward understanding positional power and coordination capacity (Fischer & Guy, 2009; Coenen & Truffer, 2012).

By foregrounding issues of power, authority, and institutional role within network structures, our findings contribute to the growing literature on the political economy of innovation ecosystems and provide an empirical basis for designing better-aligned collaborative structures in the governance of complex sustainability transitions.

5.2 Managerial and policy implications

The findings of this study offer several strategic insights for managers—particularly those operating within or seeking to join Horizon Europe-funded collaborations for the CE. Our results show that private firms, although central to the implementation of CE innovations, play a relatively peripheral role in initiating collaborations within the IECE. This suggests an untapped opportunity for firms to more actively shape innovation trajectories and influence project design phases.

Firms seeking to improve their centrality within the IECE should consider strengthening their coordination capabilities—whether through internal capacity-building or partnerships with research centres and universities, which play a prominent brokerage role in the network. By aligning with these high-centrality actors, private firms can benefit from increased visibility, knowledge spillovers, and access to complementary resources. Such alignment can also foster legitimacy within EU-funded programmes, increasing the likelihood of funding success and facilitating long-term participation in the ecosystem.

Moreover, participation in the IECE generates positive externalities that extend beyond individual projects. It embeds firms within a dynamic environment of knowledge exchange and regulatory innovation, potentially accelerating organizational learning and improving responsiveness to future sustainability regulations. These benefits are magnified in cases where firms partner with public or academic institutions that hold established records of project coordination. Managers should thus view IECE participation not just as a funding opportunity but as a strategic investment in long-term innovation capabilities and stakeholder integration.

The structural misalignment paradox identified in our study also carries significant implications for the design and governance of collaborative innovation programmes. At its core, the paradox reveals that the actors with the formal authority to drive socio-technical transitions—namely public institutions—are structurally marginalized, while those with limited regulatory influence dominate central coordination roles. This imbalance reduces the system's capacity to translate experimental knowledge into scalable, system-wide change.

To address this, policymakers should embed structural incentives into Horizon Europe's design that reward coordination by public authorities. One option is to incorporate brokerage incentives directly into evaluation criteria, granting additional points to consortia that place public actors in high-betweenness or bridging positions. This would operationalize the EU's commitment to quadruple-helix collaboration and move beyond symbolic inclusion.

In addition, capacity-building interventions are needed to support under-connected public-sector actors. Programmes such as short-term coordination fellowships (6–12 months) could embed municipal or regional officers within experienced research institutions, fostering knowledge transfer and improving their network position. Evidence from similar arrangements in innovation policy (e.g., secondments under the UK's Catapult programme or the Dutch Topsectoren) suggests that such cross-sector exposure increases absorptive capacity and improves policy-research alignment (Flanagan & Uyarra, 2016).

Regulatory sandboxes and living labs could be scaled up as part of flagship CE calls. These environments enable public actors to experiment with policies in parallel with technological innovation, reducing the temporal lag between experimentation and rule-making. Prior studies show that regulatory experimentation enhances the legitimacy and scalability of sustainability solutions, especially in sectors with high uncertainty and path dependency (Sabel & Zeitlin, 2012; Borrás & Edler, 2020).

From a national policy standpoint, there is a need to align incentives for participation with each country's CE maturity level. Our results show that frontrunners in CE deployment (e.g., Sweden, Finland, the Netherlands) are not central in the IECE network, suggesting that Horizon Europe's structure may not adequately engage these actors. This under-engagement risks fragmenting Europe's innovation landscape, limiting knowledge diffusion, and delaying CE transition. National governments should consider complementary policies that address their own institutional constraints—such as administrative burden, low absorption capacity, or weak networks—and that tailor collaboration incentives to local conditions.

Finally, the disconnection of public institutions from core innovation nodes poses a critical threat to the credibility, efficiency, and democratic legitimacy of CE policy. To reverse this trend, governments should promote secondments in the opposite direction—for instance, placing sustainability managers from companies into public agencies to co-develop regulatory frameworks. These interactions help align innovation practices with policy priorities and ensure that regulatory pathways are grounded in technical realities.

6. Conclusions, limitations and future research

This paper explored the configuration of collaboration patterns in the European IECE. Based on the Horizon Europe programme, this study analyses 276 projects contributing to the transition to CE models. The study hinged on a multilevel network analysis that looks at the country and organisational levels and considers the different types of agents in the IECE. Hence, by obtaining relevant insights into the networks' macro and microstructure, which enabled a deep understanding of the collaboration patterns between economic agents in IECEs, this study offers relevant policy and managerial implications by unveiling how economic resources are distributed and interconnection patterns are configured.

The novelty of this study contributes to the ecosystems and CE literature, delving into the importance of IEs in the development of CE and showing the deficiencies occurring in the connection between the different components of these networks. As indicated by the existing literature, given the degree of innovation and cultural change that the CE implies, all the system components must work together in its development. The IECEs could cover this collaboration. However, the results show discrepancies in the degree of collaboration by type of entity and geographical location, showing those aspects that need to be improved so that IECEs can be the fundamental piece of the development of the CE business model. Therefore, although the creation of networks, as supported by various research, is fundamental for the proper development of the CE and also allows for the correction of possible failures, it is not working to the desired degree due to these imbalances in the degree of involvement and support of the different agents.

This work is not without limitations. It is important to consider the static perspective of the analysis, given that Horizon Europe has just begun. If this comes at the advantage of offering a detailed account of how the IECE has developed under Horizon Europe since its beginnings, further analysis in subsequent years could contemplate evaluating the evolution of the strategy over time to evaluate whether and, if so, how the IECE changes.

The scope of the paper should also be mentioned. This work analyses the collaboration patterns within the European IECEs stimulated by the Horizon Europe programme. Therefore, collaboration patterns outside of this IE are beyond the scope of this work. Furthermore, to fully understand and analyse collaboration between actors under the programme, it would be beneficial to have access to data on all projects, even those that were not funded. This could contribute to a more precise representation of networks and collaborations amongst actors in the European IECE. Projects may fail to receive funding due to various reasons, and there may be unobserved variables at play (e.g., higher level of experience in submitting applications, specific characteristics of the profile of the participants in the consortia that give them an advantage in the evaluation process). The limitations we have just highlighted should be seen as a call for greater transparency and data sharing, including, for instance, providing information on all projects submitted for each funding call. Additionally, databases should contain data on aspects like the points awarded to the project at the evaluation stage or the reason for rejection. We expect this to help researchers better understand the collaboration patterns within IECEs.

Also, additional research is needed to better understand IECEs at the country level. Further network analysis can hinge on a regional or local level disaggregation to identify key nodes within countries, enhancing the picture of economic agents spearheading innovation in CE (Ferrer-Serrano et al., 2025). Finally, standardised KPIs should be established to measure CE. Not only to monitor and compare CE practices but also to evaluate the effectiveness of projects funded by the programme.

Finally, future research could further explore the role of institutional heterogeneity in shaping participation dynamics within the IECE. While our exploratory analysis in Figure 10 examined correlations between organizational participation and broad cultural or institutional variables (participation; coordination; individualism; and institutional quality), we did not identify any consistent or interpretable patterns. This suggests that the relationship may be more complex or mediated by additional factors not captured in our current framework. Subsequent studies could adopt comparative institutional approaches to investigate how national administrative cultures, norms of collaboration, and public management capacities condition actors' engagement and position within the IECE. Mixed-methods designs that combine network metrics with qualitative case studies or survey-based measures of organizational culture could provide deeper insights into how formal and informal institutional dimensions influence participation and coordination strategies. In doing so, future research would not only refine our understanding of participation asymmetries but also inform the design of context-sensitive policy tools to promote more inclusive and functionally balanced ecosystems.

Insert Figure 10 around here

References

Alka, T. A., Raman, R., & Suresh, M. (2024). Research trends in innovation ecosystem and circular economy. *Discover Sustainability*, *5*(1). https://doi.org/10.1007/s43621-024-00535-5

Aouinaït, C. (2021). Collaboration – collaborative and open innovation in highly competitive contexts. *Innovation Economics, Engineering and Management Handbook 1: Main Themes*, 91–99.

Arranz, N., F. Arroyabe, C., & Fernandez de Arroyabe, J. C. (2019). The effect of regional factors in the development of eco-innovations in the firm. *Business Strategy and the Environment, 28*(7), 1406–1415.

Baglieri, D., Baldi, F., & Tucci, C. L. (2018). University technology transfer office business models: One size does not fit all. *Technovation, 76*, 51-63.

Baldwin, C. Y., Bogers, M. L., Kapoor, R., & West, J. (2024). Focusing the ecosystem lens on innovation studies. *Research Policy, 53*(3), 104949. Forthcoming.

Barreiro-Gen, M., & Lozano, R. (2020). How circular is the circular economy? Analysing the implementation of circular economy in organisations. *Business Strategy and the Environment, 29*(8), 3484–3494.

Beauchamp, M. A. (1965). An improved index of centrality. *Behavioral Science, 10*(2), 161–163.

Blomsma, F., & Brennan, G. (2017). The Emergence of Circular Economy: A New Framing Around Prolonging Resource Productivity. *Journal of Industrial Ecology, 21*(3), 603–614.

Bocken, N. M., Olivetti, E. A., Cullen, J. M., Potting, J., & Lifset, R. (2017). Taking the Circularity to the Next Level: A Special Issue on the Circular Economy. *Journal of Industrial Ecology, 21*(3), 476-482.

Bolatan, G. I. S., Golgeci, I., Arslan, A., Tatoglu, E., Zaim, S., & Gozlu, S. (2022). Unlocking the relationships between strategic planning, leadership and technology transfer competence: the mediating role of strategic quality management. *Journal of Knowledge Management, 26*(11) 89-113.

Bonacich, P. (1987). Power and centrality: A family of measures. *American Journal of Sociology, 92*(5), 1170–1182.

Borrás, S., & Edquist, C. (2013). The choice of innovation policy instruments. *Technological Forecasting and Social Change, 80*(8), 1513–1522.

Calisto Friant, M., Vermeulen, W. J. V., & Salomone, R. (2020). A typology of circular economy discourses: Navigating the diverse visions of a contested paradigm. *Resources, Conservation and Recycling, 161*, 104917.

Cassetta, E., Dileo, I., & Pini, M. (2023). Linking external collaborations, eco-innovation and sustainable growth. An empirical analysis on the Italian manufacturing firms. *Industry and Innovation*, *30*(4), 452–479.

Cecere, G., & Corrocher, N. (2016). Stringency of regulation and innovation in waste management: An empirical analysis on EU countries. *Industry and Innovation*, *23*(7), 625–646.

Circle Economy. (2023). The Circularity Gap Report 2023. https://www.circularity-gap.world

Coccia, M. (2019). Why do nations produce science advances and new technology?. *Technology in Society, 59*, 101124.

Coenen, L., & Truffer, B. (2012). Places and Spaces of Sustainability Transitions: Geographical Contributions to an Emerging Research and Policy Field. *European Planning Studies, 20*(3), 367–374.

Crescenzi, R., Iammarino, S., Ioramashvili, C., Rodríguez-Pose, A., & Storper, M. (2019). The geography of innovation: local hotspots and global innovation networks. *World Intellectual Property Organization (WIPO) Economic Research Working Paper Series*, (57).

Del Vecchio, P., Passiante, G., Barberio, G., & Innella, C. (2020). Digital Innovation Ecosystems for Circular Economy: the Case of ICESP, the Italian Circular Economy Stakeholder Platform. *International Journal of Innovation and Technology Management, 18*(01), 2050053.

Despeisse, M., Baumers, M., Brown, P., Charnley, F., Ford, S. J., Garmulewicz, A., … Rowley, J. (2017). Unlocking value for a circular economy through 3D printing: A research agenda. *Technological Forecasting and Social Change, 115*, 75–84.

Dhanaraj, C., & Parkhe, A. (2006). Orchestrating innovation networks. *Academy of Management Review, 31*(3), 659-669.

Domenech, T., Bleischwitz, R., Doranova, A., Panayotopoulos, D., & Roman, L. (2019). Mapping Industrial Symbiosis Development in Europe_ typologies of networks, characteristics, performance and contribution to the Circular Economy. *Resources, Conservation and Recycling*, *141*, 76–98.

Dorrego-Viera, J. I., Urbinati, A., & Lazzarotti, V. (2025). Transition towards circular economy: Exploiting open innovation for circular product development. *Journal of Innovation & Knowledge*, *10*(2), 100668. https://doi.org/10.1016/j.jik.2025.100668

Edler, J., Ostertag, K., & Schuler, J. (2024). Social innovation, transformation, and public policy: towards a conceptualization and critical appraisal. *Science and Public Policy, 51*(1), 80-88.

Ellen MacArthur Foundation. (2013). Circularity Indicators: An Approach to Measuring Circularity. http://www.ellenmacarthurfoundation.org/circularity-indicators/.

Ellen MacArthur Foundation. (2020). The Global Commitment 2020 Progress Report. 76. https://emf.thirdlight.com/link/il0mcm1dqjtn-knjubr/@/preview/1?o

European Commission. (2021a, March 19). Horizon Europe. The EU Research & Innovation Programme 2021-27. https://research-and-innovation.ec.europa.eu/system/files/2022-06/ec_rtd_he-investing-to-shape-our-future_0.pdf

European Commission. (2021b, July 14). The European Green Deal. Retrieved February 4, 2024, from https://commission.europa.eu/strategy-and-policy/eu-budget/performance-and-reporting/programme-performance-statements/horizon-europe-performance_en

European Union. (2020). A new Circular Economy Action Plan For a cleaner and more competitive Europe. https://eur-lex.europa.eu/resource.html?uri=cellar:9903b325-6388-11ea-b735-01aa75ed71a1.0017.02/DOC_1&format=PDF

Farinha, L., Ferreira, J., & Gouveia, B. (2016). Networks of innovation and competitiveness: a triple helix case study. *Journal of the Knowledge Economy, 7*, 259-275.

Ferrer-Serrano, M., Fuentelsaz, L., & Gil-Lamata, M. (2024). More digitalization does not always imply more technology transfer: An analysis within the horizon Europe strategy. *The Journal of Technology Transfer*, 1-27.

Ferrer-Serrano, M., Fuentelsaz, L., & Latorre-Martinez, M. P. (2022). Examining knowledge transfer and networks: An overview of the last twenty years. *Journal of Knowledge Management, 26*(8), 2007-2037.

Ferrer-Serrano, M., Latorre-Martínez, M. P., & Fuentelsaz, L. (2021). The European research landscape under the Horizon 2020 Lenses: the interaction between science centers, public institutions, and industry. *The Journal of Technology Transfer, 46*(3), 828-853.

Ferrer-Serrano, M., Latorre-Martinez, M. P., & Fuentelsaz, L. (2025). Regional knowledge asymmetries and innovation performance from collaborations across European regions. *The Journal of Technology Transfer,* 1-33.

Ferrer-Serrano, M., & Salesa, A. (2025). Revisiting the Circular Economy Paradox: A Triple Bottom Line Perspective. *Sustainable Development*. https://doi.org/10.1002/sd.3539

Fischer, M. M., & Guy, C. (2009). Innovation, networks, and knowledge spillovers: Selected essays. Springer.

Fitjar, R. D., & Rodríguez-Pose, A. (2014). The geographical dimension of innovation collaboration: Networking and innovation in Norway. *Urban Studies*, *51*(12), 2572–2595.

França, A., López-Manuel, L., Sartal, A., & Vázquez, X. H. (2023). Adapting corporations to climate change: How decarbonisation impacts the business strategy–performance nexus. *Business Strategy and the Environment.* Forthcoming.

Freeman, L. C. (1977). A set of measures of centrality based on betweenness. *Sociometry, 40*(1), 35–41.

Fuller, J., Jacobides, M. G., & Reeves, M. (2022). The myths and realities of business ecosystems. *Business Ecosystems*, 3–11.

García-Granero, E. M., Piedra-Muñoz, L., Galdeano-Gómez, E., & Sorroche-Del-Rey, Y. (2025). A path towards sustainability through the circular economy phenom: indicators from the Spanish agri-food sector. *Sustainability Accounting Management And Policy Journal*, *16*(7), 28-61. https://doi.org/10.1108/sampj-05-2024-0509

Glückler, J., Shearmur, R., & Martinus, K. (2022). From liability to opportunity: Reconceptualizing the role of periphery in innovation. Journal of Economic Geography, 23(1), 231–257. https://doi.org/10.1093/jeg/lbac002

Granovetter, M. S. (1983). The strength of weak ties: A network theory revisited. Sociological Theory, 1, 201–233. https://doi.org/10.2307/202051

Han, D., Konietzko, J., Dijk, M., & Bocken, N. (2023). How do circular start-ups achieve scale? *Sustainable Production and Consumption, 40*, 363-375.

Hanley, A., & Semrau, F. O. (2022). Stepping up to the mark? Firms' export activity and environmental innovation in 14 European countries. *Industry and Innovation*, *29*(5), 672–700.

Harris, S., Martin, M., & Diener, D. (2021). Circularity for circularity's sake? Scoping review of assessment methods for environmental performance in the circular economy. *Sustainable Production and Consumption, 26*, 172–186.

Hartley, K., van Santen, R., & Kirchherr, J. (2020). Policies for transitioning towards a circular economy: Expectations from the European Union (EU). *Resources Conservation and Recycling, 155*.

He, J., & He, Z. (2025). Digital transformation effects on Chinese heavily polluting firms internalising environmental costs. *Sustainability Accounting Management and Policy Journal*. https://doi.org/10.1108/sampj-11-2023-0863

Herrero-Luna, S., Latorre-Martinez, M., & Ferrer-Serrano, M. (2022). Circular Economy and Innovation: A Systematic Literature Review. *Central European Business Review,* (ART-2022-128647).

Huggins, R., Johnston, A., & Stride, C. (2012). Knowledge networks and universities: Locational and organisational aspects of knowledge transfer interactions. *Entrepreneurship & Regional Development, 24*(7-8), 475-502.

Inkpen, A. C., & Tsang, E. W. (2005). Social capital, networks, and knowledge transfer. *Academy of Management Review, 30*(1), 146-165.

Jacobides, M. G., Cennamo, C., & Gawer, A. (2018). Towards a theory of ecosystems. *Strategic Management Journal, 39*(8), 2255–2276.

Jakobsen, S., Lauvås, T., Quatraro, F., Rasmussen, E., & Steinmo, M. (2021). Innovation for a Circular Economy. *Research Handbook of Innovation for a Circular Economy.*

Jambeck, J. R., Geyer, R., Wilcox, C., Siegler, T. R., Perryman, M., Andrady, A., ... & Law, K. L. (2015). Plastic waste inputs from land into the ocean. *Science, 347*(6223), 768-771.

Kennedy, S., & Linnenluecke, M. K. (2022). Circular economy and resilience: A research agenda. *Business Strategy and the Environment, 31*(6), 2754–2765.

Köhler, J., Sönnichsen, S. D., & Beske-Jansen, P. (2022). Towards a collaboration framework for circular economy: The role of dynamic capabilities and open innovation. *Business Strategy and the Environment, 31*(6), 2700–2713.

Konietzko, J., Bocken, N., & Hultink, E. J. (2020). A Tool to Analyse, Ideate and Develop Circular Innovation Ecosystems. *Sustainability, 12*(1).

Korhonen, J., Honkasalo, A., & Seppälä, J. (2018). Circular Economy: The Concept and its Limitations. *Ecological Economics, 143*, 37–46.

Kotabe, M., Martin, X., & Domoto, H. (2003). Gaining from vertical partnerships: knowledge transfer, relationship duration, and supplier performance improvement in the US and Japanese automotive industries. *Strategic Management Journal, 24*(4), 293-316.

Kuhlmann, M., Bening, C. R., & Hoffmann, V. H. (2023). How incumbents realise disruptive circular innovation - Overcoming the innovator's dilemma for a circular economy. *Business Strategy and the Environment, 32*(3), 1106–1121.

Kuhlmann, S., & Rip, A. (2018). Next-generation innovation policy and grand challenges. *Science and Public Policy, 45*(4), 448–454.

Lepori, B., Reale, E., & Bitondo, D. (2007). Comparing the evolution of national public research policies: what patterns of change?. *Science and Public Policy, 34*(6), 372–388.

Lieder, M., Asif, F. M. A., & Rashid, A. (2017). Towards Circular Economy implementation: an agent-based simulation approach for business model changes. *Autonomous Agents and Multi-Agent Systems, 31*(6), 1377–1402.

Linder, M., & Williander, M. (2017). Circular Business Model Innovation: Inherent Uncertainties. *Business Strategy and the Environment, 26*(2), 182–196.

López-Manuel, L., León-Mateos, F., & Sartal, A. (2020). Closing Loops, Easing Strains: Industry 4.0's Potential for Overcoming Challenges of Circularity in Manufacturing Environments. *Circular Economy for the Management of Operations* (pp. 23-47). CRC Press.

López-Manuel, L., Vázquez, X. H., & Sartal, A. (2023). Firm, industry, and country effects on CO2 emissions levels. *Business Strategy and the Environment*. Forthcoming.

Lozano, R., Bautista-Puig, N., & Barreiro-Gen, M. (2021). Elucidating a holistic and panoptic framework for analysing circular economy. *Business Strategy and the Environment, 30*(4), 1644–1654.

Matthess, M., & Kunkel, S. (2020). Structural change and digitalisation in developing countries: Conceptually linking the two transformations. *Technology in Society, 63*, 101428.

Mazzucato, M. (2018). Mission-Oriented Research & Innovation in the European Union: A problem-solving approach to fuel innovation-led growth. European Commission.

Mhatre, P., Panchal, R., Singh, A., & Bibyan, S. (2021). A systematic literature review on the circular economy initiatives in the European Union. *Sustainable Production and Consumption, 26*, 187–202.

Morseletto, P. (2020). Restorative and regenerative: Exploring the concepts in the circular economy. *Journal of Industrial Ecology, 24*(4), 763–773.

Nan, M., & Huang, L. (2024). Innovation Ecosystems: A Cross-Industry Examination of Knowledge Flows and Collaboration Dynamics. *Journal of the Knowledge Economy*, 1-39.

Nepelski, D., & Piroli, G. (2018). Organisational diversity and innovation potential of EU-funded research projects. *The Journal of Technology Transfer, 43*, 615-639.

Newman, M. E. (2006). Modularity and community structure in networks. *Proceedings of the National Academy of Sciences, 103*(23), 8577-8582.

Pollard, J., Osmani, M., Grubnic, S., Díaz, A. I., Grobe, K., Kaba, A., … Panchal, R. (2023). Implementing a circular economy business model canvas in the electrical and electronic manufacturing sector: A case study approach. *Sustainable Production and Consumption, 36*, 17–31.

Prieto-Sandoval, V., Jaca, C., Santos, J., Baumgartner, R. J., & Ormazabal, M. (2019). Key strategies, resources, and capabilities for implementing circular economy in industrial small and medium enterprises. *Corporate Social Responsibility and Environmental Management, 26*(6), 1473–1484.

Quatraro, F., & Ricci, A. (2023). Heterogeneity of green expenditure, firms' performances and wages: Italian evidence on circular economy, resource-saving and energy efficiency investments. Roma, Inapp. https://oa.inapp.org/xmlui/handle/20.500.12916/4152

Radu, C., & Lux, G. (2024). Circular economy promotion and disclosure among Canadian municipalities. *Sustainability Accounting Management and Policy Journal*. https://doi.org/10.1108/sampj-06-2023-0445

Ranjbari, M., Esfandabadi, Z. S., Siebers, P. O., Pisano, P., & Quatraro, F. (2024). Digitally enabled food sharing platforms towards effective waste management in a circular economy: A system dynamics simulation model. *Technovation.* Forthcoming.

Ritala, P. (2023). Grand challenges and platform ecosystems: Scaling solutions for wicked ecological and societal problems. *Journal of Product Innovation Management.* Forthcoming.

Sabel, C. F., & Zeitlin, J. (2012). Experimentalist Governance. In D. Levi-Faur (Ed.), The Oxford Handbook of Governance (pp. 169–183). Oxford University Press.

Salesa, A., León, R., & Moneva, J. M. (2022). Is Business Research Shaping the Circle? Systematic and Bibliometric Review of Circular Economy Research. *Sustainability, 14*(14), 8306.

Salesa, A., León, R., & Moneva, J. M. (2023). Airlines practices to incorporate circular economy principles into the waste management system. *Corporate Social Responsibility and Environmental Management, 30*(1), 443–458.

Scarpellini, S., Marín-Vinuesa, L. M., Aranda-Usón, A., & Portillo-Tarragona, P. (2020). Dynamic capabilities and environmental accounting for the circular economy in businesses. *Sustainability Accounting Management and Policy Journal*, *11*(7), 1129–1158. https://doi.org/10.1108/sampj-04-2019-0150

Schot, J., & Steinmueller, E. W. (2018). Three frames for innovation policy: R&D, systems of innovation and transformative change. *Research Policy, 47*(9), 1554–1567.

Schultz, F. C., & Reinhardt, R. J. (2022). Facilitating systemic eco-innovation to pave the way for a circular economy: A qualitative-empirical study on barriers and drivers in the European polyurethane industry. *Journal of Industrial Ecology*, 26, 1646–1675. https://doi.org/10.1111/jiec.13299

Snorek, J., Guerrero, A. M., Bodin, Ö., & Lubell, M. (2022). Care-based leadership in a core–periphery network: Transforming collaboration for social–ecological resilience. Ecology and Society, 27(4), 34. https://doi.org/10.5751/ES-13517-270434

Stahel, W. R. (2016). The circular economy. *Nature, 531*(7595), 435–438.

Suchek, N., Fernandes, C. I., Kraus, S., Filser, M., & Sjögrén, H. (2021). Innovation and the circular economy: A systematic literature review. *Business Strategy and the Environment, 30*(8), 3686–3702.

Swan, J., Newell, S., Scarbrough, H., & Hislop, D. (1999). Knowledge management and innovation: networks and networking. *Journal of Knowledge Management, 3*(4), 262-275.

Tsai, W. (2001). Knowledge transfer in intraorganizational networks: Effects of network position and absorptive capacity on business unit innovation and performance. *Academy of Management Journal, 44*(5), 996-1004.

Tsolakis, N., Harrington, T. S., & Srai, J. S. (2023). Digital supply network design: a Circular Economy 4.0 decision-making system for real-world challenges. *Production Planning & Control, 34*(10), 941-966.

Tsouri, M., & Pegoretti, G. (2021). Structure and resilience of local knowledge networks: the case of the ICT network in Trentino. *Industry and Innovation, 28*(7), 860-879.

Weber, K. M., & Rohracher, H. (2012). Legitimizing research, technology and innovation policies for transformative change. *Research Policy, 41*(6), 1037–1047.

Xu, G., Hu, W., Qiao, Y., & Zhou, Y. (2020). Mapping an innovation ecosystem using network clustering and community identification: a multi-layered framework. *Scientometrics, 124*(3), 2057-2081.

Appendix I: Countries codification

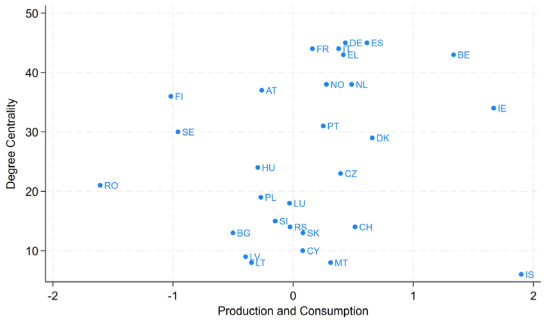
Code	Country	Code	Country
AT	Austria	IT	Italy
BE	Belgium	LT	Lithuania
BG	Bulgaria	LU	Luxembourg
CH	Switzerland	LV	Latvia
CY	Cyprus	MT	Malta
CZ	Czechia	NL	Netherlands
DE	Germany	NO	Norway
DK	Denmark	PL	Poland
EL	Greece	PT	Portugal
ES	Spain	RO	Romania
FI	Finland	RS	Serbia
FR	France	SE	Sweden
HR	Croatia	SI	Slovenia
HU	Hungary	SK	Slovakia
IE	Ireland	UK	United Kingdom
IS	Iceland		

*Excluded countries from our sample: AR, BR, BW, CA, CL, CM, CN, CO, CV, EC, ET, IL, JP, KE, KR, MA, MD, ME, MK, MY, NG, RS, RW, SL, SN, TH, TR, TZ, UA, UG, US, ZA

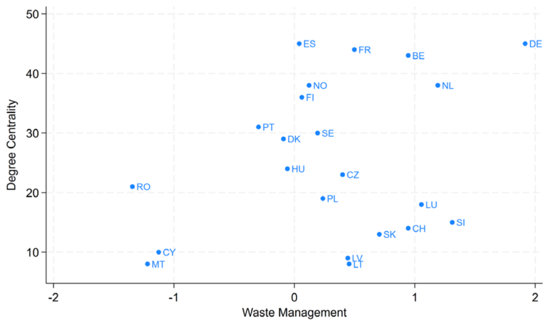
Appendix II: The Circular Economy across EU Countries

This Appendix explores European Countries' current progress towards a CE. For this purpose, we build four composite indexes based on the pillars of the monitoring framework established by the European Commission[9]. These are (i) production and consumption, (ii) waste management, (iii) secondary raw materials, and (iv) competitiveness and innovation. For the construction of our composite indexes, we select those single indicators within each pillar that (i) are available for the year 2021 and (ii) offer information disaggregated at the country level. Each composite index is the average of the standardised single indicators. Below, each composite index is plotted against degree centrality – the conventional indicator for understanding the position of agents within a network.

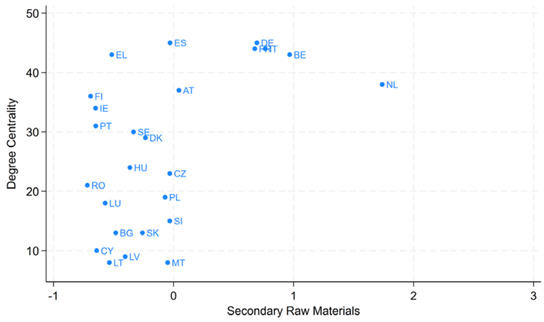
Degree centrality and production and consumption



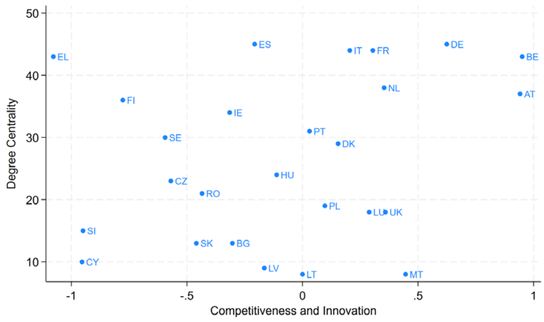
Degree centrality and waste management



Degree centrality and Secondary Raw Materials



Degree centrality and competitiveness and innovation



[9] More information: https://ec.europa.eu/eurostat/web/circular-economy/database