Driving Agricultural Innovation: The Role of Collaborative Networks in the INTERIOR+ Project under the Triple Helix Framework

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Abstract Fostering and developing agricultural innovation is critical to addressing global challenges such as food security, climate change, and sustainable development. This study adopted a descriptive case study design combining document analysis and semi-structured interviews with representatives from academia, industry, and government involved in the INTERIOR+ project. It explores the potential of

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cross-sectoral collaboration within a triple helix context to accelerate the adoption of innovative practices and technologies in the agriculture sector. The analysis identified key collaborative mechanisms, knowledge sharing, digital connectivity, and stakeholder intermediation, that enhance innovation capacity in low-density agricultural territories. Findings show that integrating Collaborative Innovation Networks (COINs) within a Triple Helix framework fosters resilience, accelerates technology adoption, and supports sustainable rural development. Moreover, the study provides practical insights on how to establish and sustain these networks, highlighting the critical role of stakeholders in leveraging the potential of COINs and cross-sectoral collaboration to propel agricultural innovation and development, and, therefore, in designing an intersectoral collaboration strategy.

Keywords Collaborative innovation network · Triple helix · Agriculture innovation systems · Rural development · Low-density territories

1 Introduction

The concept of Collaborative Innovation Networks (COINs) has emerged as a significant area of study within the broader field of innovation ecosystems. In particular, COINs have been identified as a promising approach for fostering knowledge-sharing and joint problem-solving among diverse stakeholders [1, 2]. The fundamental premise of COINs is to convene participants from disparate fields and sectors with the objective of propelling innovation in a manner that is more efficacious and inclusive than the isolated pursuit of such endeavours [3–5].

The open innovation models that underpin COINs present distinctive prospects for small and medium-sized enterprises (SMEs) to engage in collaborative endeavours and capitalise on external expertise [6]. Such collaboration fosters a more dynamic and resilient ecosystem, which is of particular importance in industries such as agriculture, where innovation can directly impact productivity and sustainability [7–10]. The existing literature on COINs emphasises the significance of inter-organisational knowledge sharing and collaborative R&D as pivotal drivers of innovation, disseminating success stories, and the benefits of digital tools that facilitate collaboration represent a key strategy for fostering innovation within COINs [11–13]. Such mechanisms facilitate accelerated innovation cycles and enhanced accessibility to state-of-the-art solution.

The role of collaborative spaces within COINs demonstrates how organisations can unite to address shared concerns [13]. Such spaces are of critical importance for the creation of networks in which innovation can flourish, enabling the pooling of resources and expertise that are often fragmented across sectors. Furthermore, the literature emphasises the inclusivity of these networks, which are perceived as a means of encouraging the participation of smaller, frequently underrepresented actors in the innovation process [14–16].

The COINs have been the subject of extensive investigation within sectors characterised by a constant imperative for adaptation and innovation. One such sector is agriculture, where the collaboration between farmers, researchers, agribusinesses, and policymakers is paramount in addressing challenges such as climate change and food security [7, 8, 10, 17]. In a rapidly evolving world facing challenges such as climate change, food security and sustainability, agricultural innovation is no longer an option but a necessity [9]. COINs, which facilitate partnerships between different stakeholders [4, 5, 18], such as farmers, researchers, agribusinesses and policymakers, provide the collaborative platforms needed to tackle complex problems that no single entity can solve alone. They have become essential for driving innovation in various sectors, and their importance in agriculture is particularly profound [17] since they are able to address urgent global challenges and significantly enhance the performance of agricultural value chains. The integration of different stakeholders ensures that innovation is inclusive and benefits all members of the chain, including smallholder farmers and agribusinesses. The formation of COINs permits cross-sectoral collaboration, which is essential for responding to challenges such as climate change and resource depletion [17]. By fostering knowledge sharing, resource pooling and collaborative problem solving, these networks can accelerate the development and adoption of new technologies and practices, ultimately leading to more productive and resilient agricultural systems [19]. Even the changing landscape of consumer behaviour as Generation Z and Alpha begin to influence markets, particularly in the agri-food sector [20]. These generations place a strong emphasis on sustainability, ethical sourcing, and technological integration. COINs are increasingly valuable in this context, as they allow agrifood businesses to collaborate with researchers and policymakers to develop sustainable and tech-driven innovations that meet the demands of younger consumers.

However, the effectiveness of COINs depends heavily on the structure and dynamics of the collaboration itself [17, 18]. This is where the triple helix model - an approach that emphasises the interplay between academia, industry and government - proves indispensable.

The triple helix framework brings together three critical sectors [21] academia, which generates research and new knowledge; industry, which applies this knowledge to create practical, scalable solutions; and government, which provides the regulatory and policy support needed to implement these innovations. In the context of agriculture, this collaboration is particularly valuable in bridging the gap between theoretical research and practical application [22]. For example, academia could develop new sustainable farming practices or resilient crop varieties, but without industry partners to commercialise these innovations and government support to create a supportive policy environment, these breakthroughs could remain in the laboratory. Without this multi-sectoral collaboration, breakthroughs could remain confined to the laboratory rather than being effectively scaled and implemented [8].

One of the key contributions of the Triple Helix model to COINs is its ability to facilitate knowledge sharing across sectors [19]. This promotion of cross-sector knowledge exchange is particularly valuable in agriculture since it is a field that requires continuous adaptation to changing environmental conditions, market

demands, and technological advancements, particularly in low-density territories (LDTs), where access to cutting-edge knowledge and technology may be limited, the Triple Helix model becomes a key mechanism for bridging the gap between local needs and global expertise [8, 23–27]. The Triple Helix framework encourages open communication and collaboration between all relevant actors, allowing them to share insights, data and strategies [21]. For example, universities researching climate-smart agriculture can share their findings with agribusinesses developing precision farming tools while governments provide the data and regulatory support needed to implement these technologies on a wider scale. Through its emphasis on collaboration across sectors, it helps build networks of connectivity that can break down these barriers. In this model, government agencies often play a crucial role by facilitating infrastructure development, offering subsidies for innovation, and creating policies that encourage public-private partnerships [24, 28]. For example, governments can prioritise the development of digital infrastructure, which is essential for COINs to function effectively in low-density territories, like in the case of the Interior+ project. Digital platforms can enable local actors to participate in virtual collaboration spaces, linking them to national and global markets, research hubs, and industrial innovation clusters [29]. This increased connectivity allows LDTs to be part of a broader innovation ecosystem, despite their geographical limitations. These regions often have untapped potentials—such as unique agricultural products, renewable energy resources, or cultural heritage—that can be harnessed through targeted innovation. By integrating the expertise of academia, the practical know-how of local industries, and the policy support of governments, COINs in low-density areas can focus on place-based innovation strategies [27].

The government's role in this process is essential, as it often provides the necessary incentives—such as innovation grants, subsidies, or tax incentives—to attract businesses and research institutions to collaborate in these regions [22]. Meanwhile, academia ensures that local populations have access to education and training programs that prepare them to participate in new industries, while local businesses can leverage academic expertise to diversify their operations and tap into new markets [30]. LDTs often face constraints when it comes to attracting investment and maintaining financial resources necessary for innovation. In the Triple Helix model, government involvement is critical to ensure that these regions receive the support they need to become innovation hubs [22]. Policies that provide incentives for research and development (R&D), particularly those targeted at sectors like agriculture, renewable energy, or rural tourism, can help align local industry interests with national and international development goals.

Another advantage of the triple helix approach in agricultural COINs is its ability to align research and development (R&D) efforts with real-world needs [21, 30]. Collaborative R&D projects between universities, industry and government can accelerate the creation and refinement of new technologies, such as drought-resistant seeds, smart irrigation systems and sustainable pest control methods. By involving all three sectors early in the innovation process, the Triple Helix model ensures that innovations are not only scientifically sound but also practical and commercially viable.

This open innovation perspective provides a valuable opportunity for businesses in agriculture to collaborate, share knowledge and leverage external expertise, ultimately fostering a more resilient and dynamic agricultural ecosystem [6]. This collaborative approach not only addresses pressing issues but also resonates with the values of the newer generation of consumers, which is very important in the agricultural sector [14]. These generations emphasise sustainability, ethical sourcing, and the integration of technology, pushing agrifood companies to innovate continually in response to these priorities. By aligning with these expectations, agrifood companies can help pave the way for a more sustainable and prosperous future for all stakeholders in the agricultural ecosystem.

The aim of this research is to demonstrate how the triple helix approach can be used to develop a collaborative innovation network in the agricultural sector. This will entail an examination of the role played by digital platforms, such as the one associated with the Interior+ project, in facilitating such collaboration.

2 Materials and Methods

The purpose of this research is to describe the strategies and practices used to facilitate and advance collaborative innovation networks involving academia, industry, and government, with a particular focus on the Triple Helix model. To this end, the study documents the implementation of these strategies, the roles of the various stakeholders, and the outcomes of collaborative efforts.

2.1 Research Method

This research followed a descriptive case study methodology. Data were collected through document analysis (policy reports, project documentation) and semi-structured interviews with 15 stakeholders from academia, industry, and government. Interviews explored collaboration practices, innovation barriers, and perceived impacts. Data were thematically analysed to identify recurring patterns in collaborative behaviour and innovation outcomes. Methodological triangulation between documentation and interview data enhanced validity and reliability.

Table 1 summarises the descriptive methodological approach used to identify and detail the practices and strategies of collaborative innovation networks operating within the Interior+ consortium and under the scope of the Triple Helix model [31].

The descriptive study offers a comprehensive overview of how collaborative innovation networks are promoted within a Triple Helix framework, providing insights into effective strategies, roles and contributions of different stakeholders (academia, industry, government), collaboration dynamics, and the impacts in the promotion of collaborative innovation networks. In addition, the description of the dynamics of collaboration within the networks, including how stakeholders interact, share

Table 1 Main research steps of the case study

Defining the scope:	Define the triple helix model and its relevance to the study, focusing on the interactions between academia, industry, and government, and identify specific collaborative networks
Specific population:	Triple helix stakeholders of a low-density territory
Data collection and analysis:	Documentation review understand: How the networks are promoted and managed, what strategies are employed to encourage participation and collaboration, the specific roles and contributions of different stakeholders within the networks

information, and work together on projects, is detailed. These data support the design of the Interior+ project's intersectoral strategy outlining potential collaborative networks, such as successful innovations or improvements in research and development processes.

2.2 Interior+ Project

The Interior+ project presents an opportunity to rethink and define a sustainable development model for rural and mountainous regions in Portugal's interior. In particular, it will address the challenges and opportunities facing these areas, with a particular focus on the Beiras and Serra da Estrela (BSE), Beira Baixa (BB), and Alto Minho (AM).

The organisation and human occupation of Portugal are the result of a complex interplay between multiple development policies and the evolution of agricultural and industrial activities over the past centuries. These territories are typified by low population density, which is indicative of the typical social and economic characteristics observed in such areas. The vicious circle that is difficult to counteract in these territories can be addressed by the creation of rural and mountain communities that bring together economic and social agents with the goal of building a more cohesive, innovative, and sustainable community in the medium and long term. It is therefore proposed that a digital platform be established, comprising pertinent content tailored to the most urgent needs of economic actors within the agricultural sector from a "Farm to Fork" perspective. This will facilitate enhanced connectivity between all stakeholders. Consequently, this will enhance the communication and training capabilities of these actors while also drawing attention to the social aspect. This is the primary objective of the Interior+ project, and it is within this context that the developed platform will be presented.

3 Results

Following a descriptive analysis, the Interior+ territory target and its agriculture sector were characterised. At the same time, a reflection was made on how COINs may fit in these low-density agriculture territories. It is possible to say that COINs can play a pivotal role in revitalising rural areas through the promotion of agricultural innovation and resilience.

3.1 Characteristics of the Portuguese Agriculture Sector

The agricultural sector in Portugal, currently eighth in turnover growth and one of the most stable in the market, reflects a trend of financial autonomy with lower economic pressures, even in a scenario of global oscillation. In 2022, the sector was composed of around 40,483 companies, which generated approximately 298,583 jobs and a turnover of around 68,994 million euros (INE-Instituto Nacional de Estatística[1]).

The companies in the sector have a predominant structure of micro and small companies, with 85.54% classified as micro companies and 11.75% as small. Medium and large companies represent, respectively, 2.28% and 0.43% of the total (INE[1]). Despite being a minority, large companies concentrate 40.35% of the turnover, suggesting high productivity and the use of advanced technology, which compensates for the smaller number of workers compared to smaller companies.

This disparity between the number of enterprises and the turnover suggests some underlying factors, such as the size of the enterprises, the type of activity carried out, and the proximity to densely populated areas and logistics centres, which directly impact regional economic performance. In 2022, the agricultural sector recorded one of the lowest rates of new business creation and a high rate of closures (84%), highlighting the difficulty of new businesses in establishing themselves in the sector and the need for supportive policies to promote sustainability and innovation (INE[1]).

Comparing the regions, the North of Portugal stood out in the creation of new companies, but the agricultural sector remained at a relatively low growth rate. In addition, individual companies predominate in the agricultural sector, which points to an entrepreneurial profile focused on family support and small operations.

In the agricultural segment, the highest concentration of companies is in Agriculture, which represents 49.47% of the companies in the sector, although it accounts for only 10.78% of the turnover and employs 27.63% of the total number of workers (INE[1]). The Agricultural Products Industry is the most economically relevant segment, corresponding to 48.79% of the turnover and concentrating 50.9% of the jobs. The Trade of Agricultural Products accounts for 40.43% of the turnover and 24.32% of the companies in the sector.

In this scenario, the Interior+ project is in a sector with a majority of micro and small businesses, of farmers and entrepreneurs mainly seeking to produce and

[1] www.ine.pt

commercialise agri-food products for family support, but also some export in collaboration with clusters and associations [32]. It has a smaller number of medium and big companies that produce nationally and internationally.

3.2 Characteristics of the Low-Density Territories of the Interior+ Project

The problem identified, for which Interior+ presents an innovative response with a view to mitigating it, is the demographic desertification of Rural Mountain Regions (RMR) of Beira Serra da Estrela (BSE), Beira Baixa (BB) and Alto Minho (AM) associated with the weak capacity to attract new talent for agricultural and agri-food and related activities. The RMR fall within the LDTs and has suffered a significant reduction in population and abandonment of activities, which are fundamental for the dynamism of these territories [33]. The disconnect in socio-economic structure is a strong constraint on rural revitalisation: the negative impact of the lack of employment opportunities in breaking the cycle of desertification. Counteracting this cycle requires transversal, concerted measures to create conditions to revitalise the territories, attracting and retaining people and retaining their value [33]. It is crucial to develop bottom-up processes appropriate to local specificities advocating rurality (EU Action Plan for Rural Regions[2]) that sustain strong, connected, resilient and prosperous rural regions. It is necessary to mobilise resources and identify the potential of territories that value human capital and that are based on knowledge transfer and recognition of their products and identity. The RMR must be constituted as an empowered and attractive local community, with citizens participating in decision-making.

All Mountain LDTs have common characteristics [34, 35]: (a) weakened agroecosystems based on small-scale and low-income family farming; (b) ageing and low-skilled workforce; (c) traditional production system without added value; (d) practices that do not facilitate environmental, economic and social sustainability contributing to their vulnerability to climate change. In addition, the primary sector has little attractiveness for investors and/or highly qualified workers who could bring the necessary innovation for the competitiveness and sustainability of the sectors associated with the agricultural and agri-food sectors [33].

The competitiveness of the agro-industrial sector depends not only on its specific performance but also on the character and degree of innovation performance, which is vital for the development of added value and differentiation in the value chain [36]. The agri-food sector, based on EU and national policies and regulations, should focus on improving competitiveness by promoting technology transfer, modernisation, innovation and quality throughout the food chain. The agri-food industry has begun to renew the concept of the role of agriculture, assuming a new paradigm

[2] https://ec.europa.eu/regional_policy/pt/newsroom/news/2021/06/30-06-2021-long-term-vision-for-rural-areas-for-stronger-connected-resilient-prosperous-eu-rural-areas

focused on the sustainable use of natural resources, the creation of public goods, equity in access to quality food, and increasingly the delivery of attractive value to society [37]. Traditions and cultural values, for example, play a decisive role in the potential of resources for the generation of value if properly used by entrepreneurs. According to this model, knowledge and development in agriculture also become a more complex and systemic concept that breaks with the model of linear relationships between stakeholders [34]. In this sense, the business has become increasingly sensitive to innovation opportunities, not only related to technological changes but also related to strategy, marketing, organisation and management.

3.3 Analysis and Discussion of the Results

Low-density regions are confronted with a distinctive set of challenges, including an ageing population, scarce resources, and geographical isolation, which collectively impede the capacity for local innovation [34, 35, 37]. In such contexts, COINs can provide indispensable platforms for the exchange of knowledge, the sharing of resources, and collaborative problem-solving, leveraging the Triple Helix model of academia, industry, and government [21, 27]. As illustrated in Fig. 1, an understanding of the theoretical background and the Interior+ proposal allows for the identification of potential roles that may contribute to the collaborative innovation network (Fig. 2).

Universities or research institutions often play a role in network promotion and management in low-density agricultural areas centred on innovation, technology advisement, and research to create accessible, centralised networks for small farmers

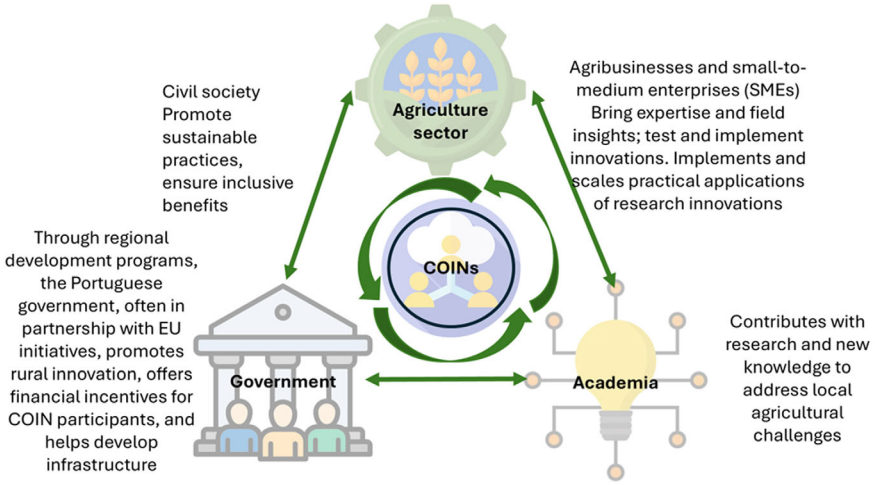

Fig. 1 Collaborative innovation networks and the main actors of the triple helix model

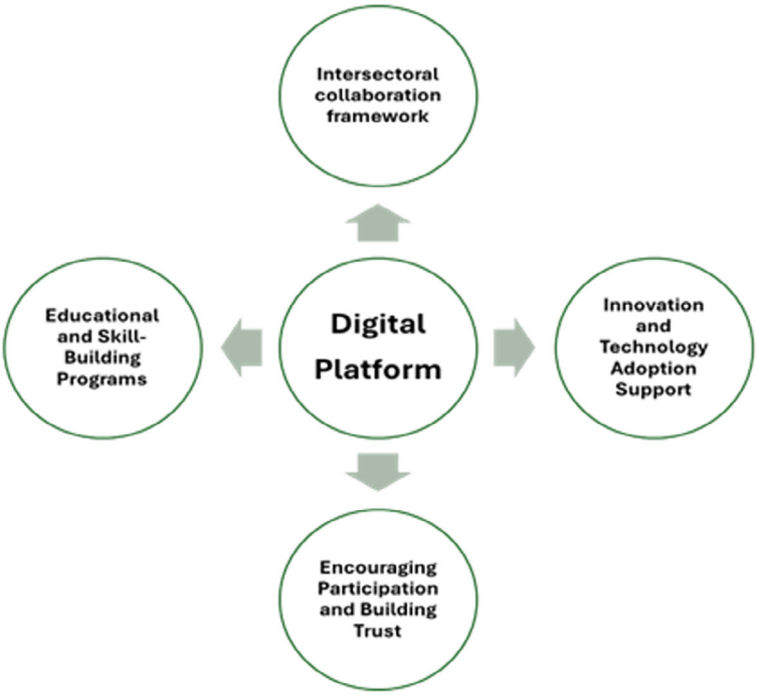

Fig. 2 Intersectoral strategy of interior + project

and entrepreneurs in remote regions, and as previously addressed in our own research [36, 38–40]. For example, the Polytechnic Institutions across Portugal often work directly with local communities to provide research-based solutions tailored to the unique needs of each area. They also lead training that allows stakeholders to develop skills to engage effectively in COINs. These agricultural innovation hubs can offer workshops, training, and demonstrations of new technologies (e.g., precision agriculture or sustainable irrigation) that are critical for smallholders who may not have easy access to such resources. There are some organisations that can play the role of "innovation brokers," helping research centres and Higher Education Institutions (HEI), such as regional development agencies, agricultural associations, and extension services, which are critical for initiating and managing networks [41]. They may serve as coordinators, connecting stakeholders from different sectors and facilitating information flow, financing, and collaboration. In low-density areas, pooled resources like shared machinery, storage facilities, or research stations enable smaller farms to benefit from advanced technology without the high individual costs [15, 16, 41]. This strategy encourages collaboration since farmers rely on shared assets and, in turn, share their knowledge and experiences with one another. Given the close-knit nature of these territories, trust-building activities like regular meetings, field visits, and joint projects help strengthen the social fabric within COINs. Trust is essential in rural areas where personal relationships are often key to successful collaboration.

In the agriculture sector, the "industry" side of the Triple Helix model is characterised by agribusinesses, most of them micro or small-to-medium enterprises (SMEs), that have a role in implementing and scaling practical applications of research innovations [32, 35]. These entities can introduce technologies like data-driven farming techniques or environmentally friendly pest control solutions, which enhance productivity and sustainability in agriculture [9, 40]. Farmers and cooperatives bring practical, on-the-ground expertise and insight into the real-world applicability of proposed innovations. Cooperatives often play a dual role, both as beneficiaries of COIN initiatives and as promoters who disseminate knowledge and technology among their members. They serve as the operational backbone of COINs, directly testing, providing feedback, and implementing innovations.

Stakeholders frequently emphasised that collaborative platforms reduce geographical isolation, enabling continuous exchange of knowledge and resources. This aligns with findings from Cronin et al. [8], and Klerkx and Leeuwis [15], who argue that structured interaction mechanisms within Triple Helix networks enhance innovation diffusion in peripheral regions. Empirical evidence from the INTERIOR+ case demonstrates that COINs facilitate the integration of local actors into broader innovation ecosystems by providing structured opportunities for collaboration and learning.

The government's role is central in low-density areas, as it provides both funding and policy support for agricultural innovation [7, 8]. Through regional development programs, the Portuguese government, often in partnership with European Union (EU) initiatives, promotes rural innovation, offers financial incentives for COIN participants, and helps develop infrastructure. Subsidies and grants from the government or EU (e.g., from the EU's Common Agricultural Policy) provide direct incentives for farmers, cooperatives, and agribusinesses to join collaborative networks. These funds encourage participation by reducing the financial risk of innovation adoption for smallholders in these regions.

Therefore, an intersectoral strategy to promote COINs is key to creating agricultural communities, fostering collaboration, and responding to challenges that are difficult to overcome as a single stakeholder. This perspective will allow to combine science and policy definitions of building resilience. The collaboration of the local government, industry, and academic resources accelerates the adoption of new technologies, making them more accessible and better suited to local needs. This will stimulate socioeconomic development through employment and business opportunities. As rural communities engage in collaborative networks, they can tap into new markets, diversify their products, and improve their livelihoods. They enable local farmers to adapt to modern challenges, contribute to environmental sustainability, and play an active role in transforming the agricultural landscape.

3.4 Intersectoral Strategy

The intersectoral strategy must emphasise the creation of a collaborative, adaptable, and resourceful environment capable of fostering ongoing innovation to encourage innovation and the implementation of technology within a digital platform aligned with the Triple Helix concept (which involves the participation of academia, industry, and government).

The Interior+ project proposes a digital platform built for collaborative innovation network promotion and an intersectoral strategy within the Triple Helix model to achieve the implementation goal of an effective network of collaboration to promote innovation and technology adoption in the agriculture sector.

Digital platforms help manage and sustain interactions in remote regions by facilitating virtual meetings, online training, and collaboration forums. These digital tools allow stakeholders in low-density areas to stay connected with broader national or international agricultural networks. The digital platform design has to have a user-centred approach, with direct input from stakeholders in an intuitive manner, to address users' specific needs and facilitate a high adoption rate. It has also ensured high standards for data management, privacy, and security to enable trust among stakeholders for data sharing and transparency in collaborative projects. This platform must be developed with different access levels and dashboards tailored to the unique needs of each Triple Helix role: academia - tools for publishing research, accessing data sets, and connecting with industry partners for collaborative R&D projects; industry - access applied research results and innovation trends and partner with startups or universities for technology development; Government - monitor innovation impacts, facilitate regulatory compliance, and fund specific projects or collaborations.

The strategy is based on a framework that establishes clear channels for cross-sector communication, including forums and workshops, where all sectors can engage in open discussions. To facilitate this communication, some "innovation brokers" have to be selected, within or outside the Interior+ partnership, to help match research or innovation needs with resources or expertise available across sectors. The platform should feature a resource hub where government funding opportunities, industry R&D tools, and academic resources (like research labs or test fields) are accessible, allowing stakeholders to leverage shared assets efficiently.

In order to facilitate the adoption and implementation of innovative technologies, academic institutions and industry partners can engage in collaborative pilot projects on the platform, which will serve to demonstrate and evaluate the efficacy of emerging technologies or innovations. It is also within the remit of government partners to ensure that these projects are in accordance with the relevant regulations and to facilitate their wider implementation. It would be beneficial to present case studies and success stories that illustrate the positive impact of new technologies on productivity, sustainability, and social outcomes. Such an approach may foster confidence among stakeholders and motivate participation. The platform can provide funding

information and technical assistance to encourage industry or academic partners to pilot or adopt new innovations that address real-world challenges.

Encouraging participation and building trust are key to creating COINs, so they enable a transparent tracking system on the platform that shows how contributions from different sectors lead to real-world outcomes in innovation, policy improvement, or economic growth. A transparent impact record encourages continuous engagement by demonstrating each sector's importance. Structured feedback mechanisms, allowing users to provide input on the platform's functionalities, collaboration experiences, and resource availability. Regularly update the platform in response to this feedback is needed to build trust in the platform's responsiveness and effectiveness.

To engage the stakeholders in the platform within an intersectoral strategy, it is necessary to offer programmes in a continuous learning environment in different areas, from innovation and technology implementation to more technical competences development in partnership with vocational education institutions. Also, hosting workshops and bringing together students, researchers, industry experts, and policymakers to work on pressing challenges collaboratively is a way to engage the stakeholders.

An intersectoral strategy focused in a digital platform within the Triple Helix framework has the potential to accelerate technology adoption by providing a centralised, adaptable, and collaborative space where academia, industry, and government each play distinct yet interconnected roles. By facilitating collaboration through structured resources, incentives, and knowledge-sharing opportunities, this platform can support dynamic, responsive innovation that meets both local needs and global challenges.

4 Conclusions

The Triple Helix model strengthens COINs in agriculture by fostering interdisciplinary collaboration and resource sharing. By integrating the expertise and resources of academia, industry, and government, this framework accelerates the pace of innovation, ensures that new technologies are both scientifically sound and commercially viable and creates a policy environment conducive to sustainable agricultural development. In a sector as critical as agriculture, where the stakes include global food security and environmental sustainability, the Triple Helix approach provides a robust foundation for driving transformative innovation.

The descriptive analysis provides insight into how a collaborative innovation network within a triple helix approach can improve technology adoption and innovation research to meet agriculture's needs, as the Interior+ project wants to do.

The findings support the Interior+ project's intersectoral strategy, which enables collaboration across sectors, not only through a triple model approach but also within industry sectors linked to agriculture that are part of its value chain.

The study demonstrates that COINs within the Triple Helix framework can strengthen innovation ecosystems in low-density agricultural territories by promoting knowledge exchange, digital collaboration, and intersectoral trust. However, as a single case study, the findings are context-specific and require further comparative analysis across regions.

Although the scientific and managerial contributions are positive, as they offer a case of structuring collaborative innovation networks within a triple model concept in the agriculture sector of RMR and LDTs, this research has the limitations of any case study and a qualitative approach.

Future research should explore quantitative indicators of network performance and the long-term impact of digital platforms on rural innovation sustainability.

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References

1. Li, X., & Liu, X. (2023). The impact of the collaborative innovation network embeddedness on enterprise green innovation performance. In *Frontiers in environmental science 11*. Frontiers. https://doi.org/10.3389/fenvs.2023.1190697
2. Song, W., Ming, X., & Wang, P. (2013). Collaborative product innovation network: Status review, framework, and technology solutions. *Concurrent Engineering Research and Applications, 21*(1), 55–64. https://doi.org/10.1177/1063293X12468457
3. Xue, X., Zhang, R., Liang, W., Fan, H., Yang, R. J., & Dai, J. (2018). Collaborative innovation in construction project: A social network perspective. *KSCE Journal of Civil Engineering, 22*, 417–427. https://doi.org/10.1007/s12205-017-1342-y
4. Xie, X., Fang, L., & Zeng, S. (2016). Collaborative innovation network and knowledge transfer performance: A fsQCA approach. *Journal of Business Research, 69*, 5210–5215. https://doi.org/10.1016/j.jbusres.2016.04.114
5. Cinelli, M., Ferraro, G., & Iovanella, A. (2019). Network processes for collaborative innovation. *International Journal of Entrepreneurship and Small Business, 36*(4), 430–452.
6. West, J., Salter, A., Vanhaverbeke, W., & Chesbrough, H. (2014). Open innovation: The next decade. *Research Policy, 43*(5), 805–811. https://doi.org/10.1016/j.respol.2014.03.001
7. Berthet, E. T., Hickey, G. M., & Klerkx, L. (2018). Opening design and innovation processes in agriculture: Insights from design and management sciences and future directions. *Agricultural Systems, 165*, 111–115. https://doi.org/10.1016/j.agsy.2018.06.004
8. Cronin, E., Fosselle, S., Rogge, E., & Home, R. (2021). An analytical framework to study multi-actor partnerships engaged in interactive innovation processes in the agriculture, forestry, and rural development sector. *Sustainability (Switzerland), 13*(11), 6428. https://doi.org/10.3390/su13116428
9. Gumbi, Nametshego, Lucas Gumbi, and Hossana Twinomurinzi. 2023. Towards sustainable digital agriculture for smallholder farmers: A systematic literature review. Sustainability (Switzerland) 15(16):12530. doi:https://doi.org/10.3390/su151612530.
10. Bitzer, V., Glasbergen, P., & Arts, B. (2013). Exploring the potential of intersectoral partnerships to improve the position of farmers in global agrifood chains: Findings from the coffee sector in Peru. *Agriculture and Human Values, 30*(1), 5–20. https://doi.org/10.1007/s10460-012-9372-z

11. Jamali, H., Dascalu, S. M., & Harris, F. C. (2024). Fostering joint innovation: A global online platform for ideas sharing and collaboration. In S. Latifi (Ed.), *ITNG 2024: 21st International Conference on Information Technology-New generations* (pp. 305–312). Springer. https://doi.org/10.1007/978-3-031-56599-1_40
12. De Falco, E., Salvatore, A. R., Orlando, B., & Cucari, N. (2017). Open collaborative innovation and digital platforms. *Production Planning & Control, 28*, 1344–1353. https://doi.org/10.1080/09537287.2017.1375143
13. Swaans, K., Boogaard, B., Bendapudi, R., Taye, H., Hendrickx, S., & Klerkx, L. (2014). Operationalizing inclusive innovation: Lessons from innovation platforms in livestock value chains in India and Mozambique. *Innovation and Development, 4*, 239–257. https://doi.org/10.1080/2157930X.2014.925246
14. Klerkx, L., Van Mierlo, B., & Leeuwis, C. (2012). Evolution of systems approaches to agricultural innovation: Concepts, analysis and interventions. In *Farming Systems Research into the 21st Century: The New Dynamic* (pp. 457–483). Springer. https://doi.org/10.1007/978-94-007-4503-2_20
15. Klerkx, L., & Leeuwis, C. (2009). Establishment and embedding of innovation brokers at different innovation system levels: Insights from the Dutch agricultural sector. *Technological Forecasting and Social Change, 76*, 849–860. https://doi.org/10.1016/J.TECHFORE.2008.10.001
16. Jialu, S., Ma, Z., Zhu, B., Xie, H., Oteng, A. F., & Hu, W. (2021). Collaborative innovation network, knowledge base, and technological innovation performance-thinking in response to COVID-19. *Frontiers in Psychology, 12*, 648276. https://doi.org/10.3389/fpsyg.2021.648276
17. Ma, H. (2023). The dynamics of China's collaborative innovation network in agricultural biotechnology: A spatial-topological perspective. *Systems, 11*(2), 73. https://doi.org/10.3390/systems11020073
18. Wang, F., Qing, S., & Zhang, Z. (2024). The influence of collaborative innovation network characteristics on firm innovation performance from the perspective of innovation ecosystem. *Kybernetes, 53*, 1281–1305. https://doi.org/10.1108/K-04-2022-0553
19. Dong, X. (2023). Research on the construction model of "innovation-network-space" industrial system of agricultural product processing in Hebei Province. *Frontiers in Business, Economics and Management, 10*, 72–75.
20. Sjahruddin, H., & Adif, R. M. (2024). Gen Z consumer trends: Understanding the next wave of buying behavior. *Management Studies and Entrepreneurship Journal, 5*, 480–485.
21. Leydesdorff, L., & Etzkowitz, H. (1998). Triple helix of innovation model. *Science and Public Policy, 25*, 358–364.
22. Li, E., Yao, F., Xi, J., & Guo, C. (2018). Evolution characteristics of government-industry-university-research cooperative innovation network for China's agriculture and influencing factors: Illustrated according to agricultural patent case. *Chinese Geographical Science, 28*, 137–152. https://doi.org/10.1007/s11769-017-0924-4
23. Etzkowitz, H., & Leydesdorff, L. (2000). The dynamics of innovation: From national systems and "mode 2" to a triple helix of university–industry–government relations. *Research Policy, 29*, 109–123. https://doi.org/10.1016/S0048-7333(99)00055-4
24. Hermans, F., Geerling-Eiff, F., Potters, J., & Klerkx, L. (2019). Public-private partnerships as systemic agricultural innovation policy instruments—Assessing their contribution to innovation system function dynamics. *NJAS-Wageningen Journal of Life Sciences, 88*, 76–95. https://doi.org/10.1016/j.njas.2018.10.001
25. Pant, L. P. (2010). Creative commons: Non-proprietary innovation triangles in international agricultural and rural development partnerships. *The Innovation Journal: The Public Sector Innovation Journal, 15*(2), 1–22.
26. Klerkx, L., Aarts, N., & Leeuwis, C. (2010). Adaptive management in agricultural innovation systems: The interactions between innovation networks and their environment. *Agricultural Systems, 103*, 390–400. https://doi.org/10.1016/J.AGSY.2010.03.012
27. Janahi, N. A., Durugbo, C. M., & Al-Jayyousi, O. R. (2022). Exploring network strategies for eco-innovation in manufacturing from a triple helix perspective. *Cleaner Logistics and Supply Chain, 4*, 100035. https://doi.org/10.1016/j.clscn.2022.100035

28. Wanzenböck, I., Wesseling, J. H., Frenken, K., Hekkert, M. P., Matthias, K., & Weber. (2020). A framework for mission-oriented innovation policy: Alternative pathways through the problem–solution space. *Science and Public Policy, 47*(4), 474–489. https://doi.org/10.1093/scipol/scaa027
29. Veile, J. W., Schmidt, M.-C., & Voigt, K.-I. (2022). Toward a new era of cooperation: How industrial digital platforms transform business models in industry 4.0. *Journal of Business Research, 143*, 387–405. https://doi.org/10.1016/j.jbusres.2021.11.062
30. Razak, A. A., & Saad, M. (2007). The role of universities in the evolution of the triple helix culture of innovation network: The case of Malaysia. *International Journal of Technology Management and Sustainable Development, 6*(3), 211–225. https://doi.org/10.1386/ijtm6.3.211/1
31. Yin, R. K. (2018). *Case study research and applications* (6th ed.). Sage Publications.
32. Paiva, T., Domingues, C., & de Andrade, L. P. (2016). Innovation and knowledge transference in a cluster user-driven innovation perspective—the Inovcluster experience. *International Journal of Food Studies, 5*, 1. https://doi.org/10.7455/ijfs/5.1.2016.a5
33. Monteiro, A. (2019). Territórios do interior, coesão territorial e modelos de governança: a propósito do programa nacional para a coesão territorial. *Sociologia on Line, 19*, 127–151. https://doi.org/10.30553/SOCIOLOGIAONLINE.2019.19.6
34. Knickel, K., Brunori, G., Rand, S., & Proost, J. (2009). Towards a better conceptual framework for innovation processes in agriculture and rural development: From linear models to systemic approaches. *The Journal of Agricultural Education and Extension, 15*, 131–146. https://doi.org/10.1080/13892240902909064
35. Coutinho, P., Simões, M., Pereira, C., & Paiva, T. (2021). Sustainable local exploitation and innovation on meat products based on the autochthonous bovine breed Jarmelista. *Sustainability, 13*, 2515. https://doi.org/10.3390/su13052515
36. Paiva, T., Ribeiro, M., & Coutinho, P. (2020). R&D Collaboration, Competitiveness Development, and Open Innovation in R&D. *Journal of Open Innovation: Technology, Market, and Complexity, 6*, 116. https://doi.org/10.3390/joitmc6040116
37. Brunori, G., Barjolle, D., Dockes, A.-C., Helmle, S., Ingram, J., Klerkx, L., Moschitz, H., Nemes, G., & Tisenkopfs, T. (2013). Reform and innovation: The role of learning and innovation networks. *EuroChoices, 12*, 27–33. https://doi.org/10.1111/1746-692X.12025
38. Gaspar, P. D., Pinheiro, R., Domingues, C., Almeida, C., Paiva, T., Pereira, C. D., & Velho, M. V. (2015). Training requirements for the agro-food industry in Portugal. *International Journal of Food Studies, 4*, 12–28. https://doi.org/10.7455/ijfs/4.1.2015.a2
39. Paiva, T., Ribeiro, M. P., & Coutinho, P. (2022). Capacity-building model to promote innovation and sustainability in the Portuguese agro-industrial sector. *Sustainability, 14*, 15873. https://doi.org/10.3390/su142315873
40. Gaspar, P. D., Soares, V. N. G. J., Caldeira, J. M. L. P., Andrade, L. P., & Soares, C. D. (2022). Technological modernization and innovation of traditional Agri-food companies based on ICT solutions—The Portuguese case study. *Journal of Food Processing and Preservation, 46*. https://doi.org/10.1111/jfpp.14271
41. Klerkx, L., van Mierlo, B., & Leeuwis, C. (2012). Evolution of systems approaches to agricultural innovation: Concepts, analysis and interventions. In I. Darnhofer, D. Gibbon, & B. Dedieu (Eds.), *Farming Systems Research into the 21st Century: The New Dynamic* (pp. 1–488). Springer.