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BLOCKCHAIN AND LOCAL TRANSFORMATION: THE FUNDÃO AGRI-FOOD ECOSYSTEM IN THE BLOCKCHAIN.PT AGENDA

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ABSTRACT

This paper investigates the role of blockchain technologies in promoting digital transformation and territorial innovation in rural contexts, using Fundão, Portugal, as a case study within the Blockchain.PT Agenda. As a recognized living lab for technological experimentation, Fundão has adopted blockchain solutions in the agri-food domain, particularly in connection with the "Cereja do Fundão" value chain, in order to reinforce product traceability, authenticity and consumer confidence. Employing a qualitative approach that combines document analysis, a literature review, and semi-structured interviews with key stakeholders, the study examines how local governance mechanisms, technology partners and agri-food actors contribute to the implementation and adaptation of blockchain solutions in the territory. By incorporating operational and value-chain perspectives, the study expands its empirical scope, offering a more comprehensive understanding of implementation dynamics, adoption challenges, and future continuity. The findings suggest that blockchain's contribution in this context lies not only in traceability itself, but also in its capacity to strengthen communication, transparency, authenticity and coordination across the agri-food ecosystem, particularly in the interaction between producers, organizations and retailers. At the same time, the results highlight important constraints, including limited pilot scalability, operational complexity in early stages, uneven digital literacy and uncertainty regarding post-project continuity. The paper concludes that, when embedded in collaborative ecosystems and supported by coherent public policies, blockchain adoption can enhance transparency and territorial innovation in low-density regions, although its long-term consolidation depends on institutional alignment, technological simplification and stakeholder engagement.

KEYWORDS

Blockchain, Local Public Administration, Rural Innovation, Agri-Food Traceability, Governance Ecosystems, Consumer Trust

1. INTRODUCTION

Rural regions across Europe continue to face major challenges related to population decline, economic fragility and limited access to digital infrastructure. In response, local public administrations are being called to lead development supported by digital transitions that are inclusive, resilient and adapted to territorial specificities (European Parliament, 2022). Among the emerging technologies explored to address these challenges, blockchain has shown promising applications in strengthening trust, transparency and local value chains (Sekuloska & Erceg, 2022). Rural development opportunities build on a common range of emerging alternatives from which they can draw, and which they may utilize in line with their specific strengths and deficiencies (Ahlmeyer & Volgmann, 2023). Emerging opportunities may help rural areas reduce or eliminate disadvantages, while also strengthening their existing advantages in comparison with urban areas (Schiefer, 2019). These dynamics are particularly visible in rural territories that function as living laboratories for technological experimentation and innovation.

This paper examines the municipality of Fundão, Portugal, which is recognized for its innovation-oriented strategy and active engagement in the Blockchain.PT Agenda (https://blockchain.void.pt/). Within this framework, Fundão has supported blockchain experimentation in the agri-food domain, particularly in connection with the "Cereja do Fundão" value chain, while also creating conditions for the extension of related solutions to other products with different levels of maturity. The study analyses the region's socioeconomic and technological context to understand how blockchain implementation can advance governance efficiency, sustainability and rural competitiveness. In this context, the adoption of blockchain is understood not only as a technological process, but also as a socio-institutional dynamic shaped by local actors, governance arrangements and value chain interactions. Empirical data were collected through four semi-structured interviews with key stakeholders, including representatives of the Municipality of Fundão (https://www.cm-fundao.pt/), Sensefinity (https://www.sensefinity.com/), a technology company participating in the Blockchain.PT consortium and directly involved in local blockchain deployment projects, Cerfundão (https://www.cerfundao.pt/pt/), a producer organization, and Vera Cruz (https://veracruzalmonds.com/), an agri-food firm.

Drawing on a systematic literature review and empirical insights from stakeholder interviews, this research analyses how blockchain is implemented in practice within rural innovation and governance contexts. The study is guided by the following research question: How can blockchain technologies promote sustainable governance and territorial innovation in rural regions such as Fundão?

2. THEORETICAL FRAMEWORK

Blockchain, as a form of distributed ledger technology (DLT), provides an infrastructure for decentralized, tamper-evident recording of transactions and interactions, thereby reducing reliance on intermediaries and strengthening data integrity (Alobid et al., 2022). Originating in the context of cryptocurrencies (Nakamoto, 2008), the technology's scope expanded significantly with the introduction of programmable smart contracts, which enabled automated and conditional execution of agreements and broadened blockchain's applicability across governance, supply-chain provenance and service orchestration (Kaur & Parashar, 2022). The

principal technical attributes of blockchain - decentralization, immutability and automation -, underpin its capacity to enhance transparency, efficiency and trust among heterogeneous network participants (Casino et al., 2019).

Complementary technologies, notably the Internet of Things (IoT) and artificial intelligence (AI), are integral to contemporary digital transformation. IoT devices capture real-time data from physical assets, enhancing traceability and enabling predictive maintenance across supply chains (Atzori et al., 2017). When anchored in immutable ledgers, these data streams become verifiable inputs for AI-driven analytics, which in turn produce actionable insights for operational optimisation and decision support (Li & Nanseki, 2022). Consequently, digital transformation should be conceived as a socio-technical reconfiguration in which technological affordances interact with organisational capabilities, regulatory settings and resource endowments to generate public value (Mahula et al., 2022). Within public administration, this process compels a shift from conventional e-government to data-driven governance models that reconcile efficiency with accountability, inclusion and democratic legitimacy (Latupeirissa et al., 2024; Mergel et al., 2019).

Rural territories confront persistent structural constraints, such as demographic decline, infrastructural deficits and limited integration into innovation networks, while simultaneously retaining comparative advantages related to primary production, cultural assets and local community ties (Firsova & Abrham, 2021). The digital transition of agriculture, often labelled Agriculture 4.0, encompasses the integration of blockchain, AI, IoT and data analytics across production, logistics and market channels (Bampasidou et al., 2024).

Collaborative governance, characterised by multi-stakeholder coordination, intermediary facilitation and public–private partnerships, emerges as a central enabler of effective adoption. Municipal authorities can provide legitimacy and convening capacity, technology firms operationalise solutions, cooperatives mobilise producers, and national programmes supply funding and scalability. Conversely, fragmented governance, inadequate connectivity, low digital literacy and misaligned incentives risk uneven uptake and the entrenchment of existing disparities (Kaur & Parashar, 2022; OECD, 2019). Empirical studies indicate that blockchain's effectiveness is amplified when combined with IoT sensing and AI analytics, improving logistics, reducing fraud and facilitating access to finance; yet infrastructural and institutional barriers remain salient (Rocha et al., 2023; Silveira et al., 2023).

In sum, governance frameworks function both as mediators and outcomes of technology adoption: they condition whether distributed technologies advance transparency, efficiency and territorial innovation, and successful implementations can, in turn, strengthen local governance capacities. For rural contexts such as Fundão, the interplay between municipal leadership, consortium partners and local cooperatives determines the extent to which blockchain initiatives produce durable socio-economic benefits.

3. METHODOLOGY

This study employs a qualitative, exploratory approach, combining a structured literature review with empirical insights from semi-structured interviews. The literature review was conducted using the Scopus and Web of Science databases. The initial search applied the query: ("emerging technologies" OR "blockchain") AND ("local administration" OR "public administration" OR "public policy") AND ("agriculture" OR "food" OR "rural development" OR "agricultural

business" OR "agro-food" OR "agribusiness"), limited to English-language articles and conference papers published between 2015 and 2025, and indexed in relevant subject areas, including Computer Science, Engineering, Business, Social Sciences, Economics, and Agricultural Sciences. From forty-five documents initially retrieved, twenty-five were selected for full-text analysis based on academic quality, thematic relevance, and alignment with the research objective. To incorporate the Portuguese context, an additional search using "Fundão" AND "Portugal" yielded twenty-one documents, two of which were included for full-text review.

Ultimately, twenty-seven documents, together with data collected through four semi-structured interviews with key stakeholders, constituted the final dataset. The interviewees included representatives of the Municipality of Fundão, Sensefinity, Cerfundão, a local producer organization associated with the "Cereja do Fundão" value chain, and Vera Cruz, an agri-food company integrated into the regional production ecosystem. This composition allowed the study to capture institutional, technological, operational and value-chain perspectives. The combination of literature and empirical evidence enables a more comprehensive understanding of how blockchain and related emerging technologies may contribute to transparency, efficiency and territorial innovation in rural agro-food systems, while also revealing the socio-institutional and operational conditions that shape their practical implementation.

The interview material was analysed through a thematic approach, focusing on recurring dimensions emerging from the empirical evidence. Particular attention was given to five analytical dimensions: territorial governance, value-chain coordination, technological integration, operational challenges and long-term continuity. This analytical structure made it possible to compare institutional, technological and business perspectives, while identifying convergences and tensions between strategic expectations and practical implementation conditions.

4. RESULTS AND DISCUSSION

Below are the findings derived from addressing the study's research question, complemented by insights from interviews with the Municipality of Fundão, Sensefinity, Cerfundão and Vera Cruz.

4.1 Fundão as a Territorial Innovation Ecosystem for Blockchain Experimentation

Blockchain technologies have been increasingly associated with enhanced transparency, traceability and coordination across agri-food value chains, particularly when combined with complementary technologies such as IoT, data analytics and artificial intelligence (Iftekhar et al., 2021; Panwar et al., 2023; Vern et al., 2025). In rural contexts, however, their transformative potential depends not only on technological capabilities, but also on governance arrangements, organizational capacity and the ability to embed digital solutions within existing territorial and productive systems.

The case of Fundão illustrates this dynamic particularly well. Fundão, a rural municipality in Portugal's Central Region with approximately 30,000 inhabitants, has strategically invested

in innovation as a driver of socio-economic transformation (Almeida & Daniel, 2023; Rodrigues & Franco, 2021). Its low-density, peripheral setting faces structural challenges common to rural territories, including demographic decline, geographic isolation and limited infrastructure. In response, the municipality has implemented a long-term development strategy centred on innovation, digitalisation and territorial competitiveness.

Since 2012, the Municipality of Fundão has promoted the "Fundão Inovação" strategy, attracting technology firms, fostering employment and diversifying the local economy, while progressively integrating digital technologies into traditional sectors such as agriculture. Initiatives such as the Agrotech Centre, the Living Lab Agrotech 4.0, the Agrotech Challenge and the Agro-Innovation Fair have positioned the territory as a testing ground for emerging technologies applied to agri-food systems (Almeida & Daniel, 2023). By 2016, the presence of multiple technology companies, including multinational firms, had contributed to increased economic dynamism, higher wages and growth in firm creation (Almeida & Daniel, 2023; Rodrigues & Franco, 2021). Complementary investments in digital education and public participation strengthened social legitimacy and community engagement, contributing to the recognition of Fundão through awards such as Municipality of the Year (2016) and the EU Region Star Award (2018) (Almeida & Daniel, 2023).

Empirical evidence reinforces the view that Fundão's relevance lies not only in its adoption of emerging technologies, but also in its capacity to convene and coordinate diverse actors around experimental initiatives. In this context, the municipality assumes a central role as a territorial facilitator, promoting articulation between technology providers, producer organizations, agri-food firms, research institutions and market actors. Rather than acting as the sole technical driver, the municipality enables the conditions for collaborative experimentation, trust-building and knowledge exchange across the local ecosystem.

This multi-actor configuration is particularly relevant in the agri-food domain, where blockchain-related initiatives have been developed within specific value chains and involve different levels of technological maturity. As the following sections demonstrate, the effectiveness of these initiatives depends not only on the technological solution itself, but also on the alignment between actors, the integration with existing systems and the capacity to translate technological potential into operational and market value.

4.2 Blockchain in the Agri-Food Value Chain: From Traceability to Communication and Market Differentiation

Blockchain-based solutions in agri-food systems are frequently associated with traceability and transparency. However, empirical evidence from the Fundão case suggests that their role extends beyond data recording, contributing to new forms of value creation, communication and market positioning across the value chain.

Initial pilot projects focused on the "Cereja do Fundão" value chain, later expanding to other products such as peaches and almonds, with exploratory applications in additional agri-food segments. From a technological perspective, the system integrates data collected through sensors in the field and during packaging processes, supported by LoRa communication networks and cloud-based storage. Information is structured according to EPCIS standards and anchored in a Hyperledger blockchain, ensuring data immutability while allowing differentiated access between public and private information.

While these technical features enable traceability, their relevance becomes more evident when translated into user-facing applications. Blockchain is operationalized through digital interfaces, such as QR codes associated with individual products, which allow consumers to access information about origin, production processes and supply chain pathways. In this sense, traceability evolves into a communication tool, reinforcing transparency and enabling more direct connections between producers and consumers.

From the perspective of producer organizations such as Cerfundão, the relevance of blockchain lies less in internal process management and more in product differentiation, origin communication and brand valorization. In the case of Cerfundão, the relevance of blockchain must be understood in relation to an already structured internal traceability system. The organization already manages information at producer, parcel and lot level, supported by certification requirements and internal control procedures. Therefore, blockchain does not replace existing traceability mechanisms. Rather, it adds an external layer of verification and communication, allowing information that is already generated internally to be translated into a more transparent and accessible format for retailers and consumers.

The ability to communicate verified information supports positioning in premium markets and strengthens consumer trust. Similarly, from the perspective of agri-food firms such as Vera Cruz, blockchain-based solutions are perceived as mechanisms to enhance product credibility and respond to increasing market demands for transparency, sustainability and authenticity.

The case of Vera Cruz further illustrates the importance of technological integration for the practical viability of blockchain solutions. The company had already explored blockchain-related applications before the current project, but earlier experiences revealed the limitations of manual data insertion. The transition towards integration between the company's ERP system and the blockchain infrastructure was therefore considered essential to ensure consistency, reduce duplication and avoid operational errors. This suggests that blockchain adoption becomes more viable when it is embedded in existing information systems rather than introduced as a parallel and additional reporting layer.

These findings suggest that blockchain adoption in the agri-food sector is not limited to efficiency gains or compliance with traceability requirements. Instead, it supports a shift towards more transparent, information-rich and market-oriented value chains, where digital technologies enable new forms of interaction, trust-building and value capture. However, as will be discussed in subsequent sections, the realization of these benefits depends on the effective integration of technological solutions into existing operational processes and on the alignment between actors across the value chain.

4.3 Multi-Actor Governance and the Role of Intermediary Organizations

The implementation of blockchain-based solutions in the Fundão case reveals that technological innovation is deeply embedded in complex governance structures involving multiple actors across the agri-food value chain. Rather than being driven solely by technological capabilities, blockchain adoption emerges as a coordinated process shaped by institutional arrangements, trust-building mechanisms and collaborative dynamics.

Empirical evidence highlights the presence of a multi-actor ecosystem that includes producers, cooperatives, logistics operators, retailers, technology providers, research institutions, educational actors and local public administration. Within this configuration, each

actor contributes distinct capabilities and resources, requiring effective coordination to ensure the functionality and sustainability of blockchain-based systems.

A central role is played by intermediary organizations, particularly the Municipality of Fundão and local producer organizations such as Cerfundão. The municipality acts as a catalyst and facilitator, promoting initial adoption, mediating relationships between stakeholders and supporting the alignment of technological solutions with territorial development strategies. This role is especially relevant in early stages of implementation, where uncertainty, resistance to change and lack of technical knowledge may hinder adoption.

In this sense, the Municipality of Fundão should not be understood as the main technical operator of the blockchain solution, but rather as a territorial orchestrator. Its contribution lies in creating favourable conditions for experimentation, connecting actors that would not necessarily collaborate otherwise, and giving institutional legitimacy to innovation processes. This facilitation role is particularly relevant in low-density territories, where individual firms and producers may lack the resources, networks or confidence required to engage independently with emerging technologies.

In parallel, producer organizations such as Cerfundão operate as key intermediaries between individual farmers and the broader value chain, enabling the aggregation of production, standardization of processes and integration of digital tools. Their involvement is critical to ensuring the operational viability of blockchain systems, particularly in contexts characterised by fragmented production structures and varying levels of digital literacy.

The governance model is further reinforced through collaborative environments such as living labs, experimental farms and applied research partnerships, which allow blockchain solutions to be tested and adapted in real production settings. These mechanisms facilitate iterative learning processes, aligning technological development with local needs and constraints.

Importantly, the Fundão case illustrates a form of place-based innovation, where blockchain is not implemented as a standalone technology, but as part of a broader territorial strategy that integrates digital transformation, human capital development and sectoral modernization. Initiatives such as digital skills programs and the integration of technology into education contribute to building long-term absorptive capacity within the region.

Overall, the findings suggest that the effectiveness of blockchain in agri-food systems depends less on the technology itself and more on the governance structures that support its implementation. Multi-actor coordination, the presence of trusted intermediaries and the alignment between technological solutions and territorial strategies emerge as key conditions for successful adoption and scaling.

4.4 Operational and Technological Challenges in Implementation and Scaling

Despite the potential associated with blockchain-enabled traceability and communication, the Fundão case also reveals significant operational and technological challenges affecting implementation and scaling. These constraints confirm that the success of blockchain-based solutions in rural agri-food systems depends not only on their conceptual value, but also on their practical compatibility with existing workflows, organizational routines and technological infrastructures.

One of the most evident challenges concerns operational complexity. In the case of Cerfundão, the initial model was perceived as generating excessive "entropy" in the system, introducing additional procedures, physical tags and logistical burdens that reduced the fluidity of existing operations.

This perception is particularly important because agri-food operations are highly time-sensitive. In the cherry value chain, for instance, product perishability, short harvesting windows and the need for rapid logistics make any additional operational step highly consequential. For this reason, technological solutions must be designed to reduce friction and support existing workflows. The interviews suggest that dynamic QR codes and more automated forms of data integration may represent a more feasible path than models based on additional physical tagging and manual procedures.

Connectivity and infrastructure limitations also emerged as important barriers. Difficulties in the functioning of tags and communication devices, together with broader constraints in rural digital infrastructure, affected the reliability and scalability of the system. These findings are consistent with the literature highlighting interoperability, connectivity and infrastructure gaps as persistent barriers to blockchain adoption in agri-food contexts (Nagariya et al., 2022; Martínez-Castañeda & Feijoo, 2023).

Another key issue concerns integration with pre-existing systems. The interviews revealed that the viability of blockchain solutions depends heavily on their capacity to connect with organizational software already in use, particularly enterprise resource planning systems and internal traceability structures. In the case of Vera Cruz, the transition from manual insertion of data into blockchain to API-based integration with the ERP was considered essential to ensure consistency, avoid duplication and reduce the risk of error. Similarly, in the case of Cerfundão, the feasibility of the solution depended on its capacity to adapt to the company's existing traceability logic, rather than replacing it entirely.

Digital literacy and uneven readiness among actors also shape adoption. Interview evidence suggests that large-scale or more technologically oriented actors tend to be more open to innovation, whereas smaller and more traditional producers often perceive additional digital requirements as burdensome. This heterogeneity affects the diffusion of blockchain solutions and reinforces the importance of intermediary organizations capable of aggregating, supporting and translating technological tools into workable practices. Previous studies have similarly shown that insufficient digital skills and uneven technological preparedness remain major obstacles to Agriculture 4.0 implementation (Silveira et al., 2023; Bampasidou et al., 2024).

Consumer engagement constitutes a further challenge. Although blockchain-based interfaces such as QR codes may potentially strengthen transparency and trust, both Cerfundão and Vera Cruz highlighted the need for clearer communication, stronger consumer literacy and more visible incentives for interaction. The available evidence suggests that the value of these tools will only materialise fully if consumers understand their purpose and perceive added value in accessing product-related information.

The interviews also suggest that consumer engagement cannot be assumed as an automatic outcome of technological transparency. Providing access to information through QR codes or landing pages does not necessarily mean that consumers will interact with that information. For these tools to generate value, the information must be understandable, visually accessible and connected to perceived benefits, such as quality assurance, sustainability claims, authenticity or promotional incentives. Retailers may therefore play an important role in mediating this interaction, particularly through in-store communication and product storytelling.

Finally, questions of continuity and scaling remain open. The interviews suggest that the pilots generated useful experimentation and proof-of-concept, but did not yet reach a scale sufficient to allow robust conclusions regarding long-term adoption or market impact. Financial sustainability, organizational alignment, technological simplification and post-project continuity therefore emerge as decisive conditions for future consolidation.

These findings also highlight the importance of the transition from pilot experimentation to long-term consolidation. While blockchain-based solutions have demonstrated their relevance as proof-of-concept initiatives, particularly in enhancing traceability and communication, their sustained adoption depends on additional factors beyond technical validation.

In particular, technological simplification and integration with existing systems emerge as critical conditions. Early models based on additional devices, tagging processes or manual data insertion may be suitable for testing purposes, but are unlikely to be sustainable in operational environments. More integrated approaches, such as ERP connections, APIs, dynamic QR codes and automated data flows, appear more compatible with the routines of agri-food actors.

Furthermore, long-term consolidation depends on the creation of tangible value for different stakeholders, including producers, organizations, retailers and consumers. This may include product differentiation, improved communication, stronger brand credibility and alignment with emerging regulatory requirements related to traceability and sustainability. The role of retailers may also be particularly relevant in creating real market contexts for validating consumer interaction and reinforcing the perceived usefulness of these solutions.

In this context, post-project continuity remains a central challenge. As the initiatives analysed are closely linked to the Blockchain.PT Agenda, their future consolidation will depend on the capacity of local actors to maintain collaboration beyond the duration of the funded project, ensuring institutional alignment, clear ownership and sustainable governance arrangements.

Overall, the Fundão case shows that blockchain adoption in rural agri-food systems is shaped by a set of interdependent technological, operational and organizational constraints. Rather than invalidating the potential of technology, these findings highlight the need for more adaptive, integrated and user-oriented implementation models capable of responding to the realities of local value chains.

4.5 SWOT Analysis of Blockchain Adoption in the Fundão Agri-Food Ecosystem

To synthesize the empirical and analytical findings, a SWOT analysis was conducted to assess the main internal and external factors influencing blockchain adoption in the Fundão agri-food ecosystem. The main strengths, weaknesses, opportunities and threats identified in the analysis are summarized in Table 1.

The analysis highlights a set of structural strengths associated with the implementation of blockchain technologies, particularly in terms of transparency, traceability and the reinforcement of consumer trust. These elements contribute to product differentiation and support access to higher-value markets. Institutional support, notably from the Municipality of Fundão, also emerges as a key enabling factor, facilitating coordination among stakeholders and promoting experimentation within a structured innovation ecosystem.

At the same time, several internal limitations persist. Blockchain implementation introduces operational complexity, particularly in the integration of digital solutions with existing production and logistics systems. Constraints related to digital literacy, especially among primary producers, and technical challenges associated with infrastructure and system interoperability further limit adoption and scalability.

From an external perspective, the current policy and market environment create important opportunities. European regulatory frameworks, such as the Digital Product Passport and the Farm to Fork Strategy, are expected to reinforce the relevance of traceability and transparency mechanisms. At the same time, growing consumer demand for sustainable and verifiable products, together with the potential integration of blockchain with complementary technologies such as IoT and artificial intelligence, opens new avenues for value creation and expansion to additional agri-food value chains.

However, the analysis also identifies relevant threats that may constrain long-term consolidation. Resistance to change among stakeholders, uneven levels of digital readiness across actors, and persistent infrastructure limitations can hinder adoption processes. Additionally, uncertainty regarding economic returns and long-term sustainability of blockchain-based solutions may reduce incentives for investment, particularly among smaller producers.

Overall, the SWOT analysis reinforces that blockchain adoption in rural agri-food systems is not solely determined by technological potential, but depends on the alignment between institutional support, stakeholder capabilities and market conditions. In this context, the Fundão case illustrates both the opportunities and the constraints associated with the implementation of emerging digital technologies in low-density territories.

Table 1. SWOT analysis of blockchain adoption in the Fundão agri-food ecosystem

Strengths	**Weaknesses**
• Transparency and traceability • Consumer trust • Product differentiation • Institutional support	• Operational complexity • System integration issues • Low digital literacy • Technical constraints
Opportunities	**Threats**
• EU policy push • Sustainable product demand • IoT and AI integration • Expansion to new value chains	• Resistance to change • Uneven digital readiness • Infrastructure gaps • Uncertain returns

5. CONCLUSION

The findings of this study suggest that blockchain adoption in rural agri-food systems should be understood not merely as a technological upgrade, but as a socio-technical and governance-dependent process. In the case of Fundão, blockchain-based solutions have shown potential to enhance transparency, traceability and consumer trust, while also creating new opportunities for communication, product differentiation and market positioning. In this sense, the value of blockchain extends beyond the secure recording of data, contributing to stronger links between producers, organizations, retailers and consumers across the value chain.

The case also demonstrates that the effectiveness of blockchain in rural contexts depends heavily on the existence of a supportive territorial innovation ecosystem. In Fundão, the municipality plays a relevant role as a facilitator of coordination, experimentation and trust-building among multiple actors, including technology providers, producer organizations and agri-food firms. This multi-actor configuration helps explain why blockchain initiatives in the territory have been able to evolve from isolated pilots towards broader experimentation in the agri-food domain, particularly in connection with the "Cereja do Fundão" value chain and its extension to other products with different levels of maturity.

At the same time, the study highlights several important constraints. Operational complexity, difficulties in integrating blockchain with existing systems, limited digital literacy among some actors, connectivity issues and uncertainty regarding long-term continuity all affect implementation and scaling. These findings reinforce the idea that technological promise alone is insufficient. Blockchain-based solutions are more likely to succeed when they are adapted to existing organizational realities, supported by intermediary structures and aligned with local capabilities, market incentives and institutional strategies.

Overall, the Fundão case shows that blockchain technologies can promote sustainable governance and territorial innovation in rural regions not only by improving traceability and transparency, but also by supporting collaborative forms of coordination, value creation and strategic differentiation. However, their long-term contribution depends on simplification, interoperability, stakeholder engagement and continuity beyond pilot stages. Future research would benefit from broader empirical designs, including additional stakeholders, comparative case studies and longitudinal approaches capable of assessing how these initiatives evolve over time and under different territorial conditions.

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REFERENCES

Ahlmeyer, F., & Volgmann, K. (2023). What Can We Expect for the Development of Rural Areas in Europe? - Trends of the Last Decade and Their Opportunities for Rural Regeneration. *Sustainability*, *15*(6). https://doi.org/10.3390/su15065485

Almeida, J., & Daniel, A. (2023). Local governance of evolutionary entrepreneurial ecosystems: A case study in a low-density territory. *Local Economy*, *38*(8), 735–754. https://doi.org/10.1177/02690942241278637

Alobid, M., Abujudeh, S., & Szűcs, I. (2022). The Role of Blockchain in Revolutionizing the Agricultural Sector. In *Sustainability (Switzerland)* (Vol. 14, Issue 7). MDPI. https://doi.org/10.3390/su14074313

Atzori, L., Iera, A., & Morabito, G. (2017). Understanding the Internet of Things: definition, potentials, and societal role of a fast evolving paradigm. *Ad Hoc Networks*, *56*, 122–140. https://doi.org/10.1016/j.adhoc.2016.12.004

Bampasidou, M., Goldgaber, D., Gentimis, T., & Mandalika, A. (2024). Overcoming 'Digital Divides': Leveraging higher education to develop next generation digital agriculture professionals. *Computers and Electronics in Agriculture*, *224*. https://doi.org/10.1016/j.compag.2024.109181

Bronson, K. (2018). Smart Farming: Including Rights Holders for Responsible Agricultural Innovation. *Technology Innovation Management Review*, *8*(2), 7–14. https://doi.org/10.22215/timreview/1135

Câmara Municipal do Fundão. (2021). *MIXin 2 Plano Municipal para a Integração de Migrantes*.

Casati, M., Soregaroli, C., Frizzi, G. L., & Stranieri, S. (2024). Impacts of blockchain technology in agrifood: exploring the interplay between transactions and firms' strategic resources. *Supply Chain Management- An International Journal*, *29*(7), 51–70. https://doi.org/10.1108/SCM-09-2023-0443

Casino, F., Dasaklis, T. K., & Patsakis, C. (2019). A systematic literature review of blockchain-based applications: Current status, classification and open issues. *Telematics and Informatics*, *36*, 55–81. https://doi.org/10.1016/J.TELE.2018.11.006

Chen, C., Gao, J., Cao, H., & Chen, W. (2024). Unpacking the agricultural innovation and diffusion for modernizing the smallholders in rural China: From the perspective of agricultural innovation system and its governance. *Journal of Rural Studies*, *110*. https://doi.org/10.1016/j.jrurstud.2024.103385

European Parliament. (2022). *Towards stronger, connected, resilient and prosperous rural areas by 2040*. https://www.europarl.europa.eu/doceo/document/A-9-2022-0269_EN.html?utm_source=chatgpt.com#_section1

European Union. (2020). *Farm to Fork Strategy*.

European Urban Initiative. (2023). *Fundão - Friendly City of Investment and Innovation*. Portico Urban Platform. https://portico.urban-initiative.eu/urban-practices/european-urban-initiative/fundao-friendly-city-investment-and-innovation-7815?utm_source=chatgpt.com

Fiore, M., & Mongiello, M. (2023). Blockchain Technology to Support Agri-Food Supply Chains: A Comprehensive Review. *IEEE Access*, *11*, 75311–75324. https://doi.org/10.1109/ACCESS.2023.3296849

Firsova, N., & Abrham, J. (2021). Economic perspectives of the Blockchain technology: Application of a SWOT analysis. *Terra Economicus*, *19*(1), 78–90. https://doi.org/10.18522/2073-6606-2021-19-1-78-90

Gonzalez-Mendes, S., Alonso-Munoz, S., Garcia-Muina, F. E., & Gonzalez-Sanchez, R. (2024). Discovering the conceptual building blocks of blockchain technology applications in the agri-food supply chain: a review and research agenda. *British Food Journal*, *126*(13), 182–206. https://doi.org/10.1108/BFJ-06-2023-0517

Iftekhar, A., Cui, X., & Yang, Y. (2021). Blockchain technology for trustworthy operations in the management of strategic grain reserves. *Foods*, *10*(10). https://doi.org/10.3390/foods10102323

Kaur, P., & Parashar, A. (2022). A Systematic Literature Review of Blockchain Technology for Smart Villages. In *Archives of Computational Methods in Engineering* (Vol. 29, Issue 4, pp. 2417–2468). Springer Science and Business Media B.V. https://doi.org/10.1007/s11831-021-09659-7

Kumar, M., Choubey, V. K., Raut, R. D., & Jagtap, S. (2023). Enablers to achieve zero hunger through IoT and blockchain technology and transform the green food supply chain systems. *Journal of Cleaner Production*, *405*. https://doi.org/10.1016/j.jclepro.2023.136894

Lai, M. B., Vergamini, D., & Brunori, G. (2025). Food Supply Chain: A Framework for the Governance of Digital Traceability. *Foods*, *14*(12), 2032. https://doi.org/10.3390/foods14122032

Lakhan, A., Mohammed, M. A., Al-Budair, L. Q. A., Memon, S., Slany, V., Deveci, M., & Martinek, R. (2025). Enhancing transparency and efficiency in blockchain harvest: Empowering farmers and consumers through transparent trading in agricultural applications. *Alexandria Engineering Journal*, *118*, 91–104. https://doi.org/10.1016/j.aej.2025.01.005

Latupeirissa, J. J. P., Dewi, N. L. Y., Prayana, I. K. R., Srikandi, M. B., Ramadiansyah, S. A., & Pramana, I. B. G. A. Y. (2024). Transforming Public Service Delivery: A Comprehensive Review of Digitization Initiatives. *Sustainability (Switzerland)*, *16*(7), 2818. https://doi.org/10.3390/SU16072818/S1

Li, D., & Nanseki, T. (2022). Review of the Practice, Promotion, and Perspective of Smart Agriculture in China. *Journal of the Faculty of Agriculture, Kyushu University*, *67*(2), 227–237. https://doi.org/10.5109/4797830

Lopes, C., Leitão, J., & Gallego, J. R. (2022). Place-Linked Products and Creative Tourism in Iberian Regions. *Tourism, Hospitality and Event Management*, 137–179. https://doi.org/10.1007/978-3-030-89232-6_8

Mahula, S., Lindquist, M., Norström, L., & Lindman, J. (2022). Digital transformation in local government organisations: Empirical evidence from blockchain initiatives. *ACM International Conference Proceeding Series*, 336–345. https://doi.org/10.1145/3543434.3543474

Mais Magazine. (2024, March 29). *O Fundão é um território de raiz e asas*. https://maismagazine.pt/index.php/2024/03/29/o-fundao-e-um-territorio-de-raiz-e-asas/

Martínez-Castañeda, M., & Feijoo, C. (2023). Use of blockchain in the agri-food value chain: State of the art in Spain and some lessons from the perspective of public support. *Telecommunications Policy*, *47*(6). https://doi.org/10.1016/j.telpol.2023.102574

Mergel, I., Edelmann, N., & Haug, N. (2019). Defining digital transformation: Results from expert interviews. *Government Information Quarterly*, *36*(4), 101385. https://doi.org/10.1016/J.GIQ.2019.06.002

Merrell, I. (2022). Blockchain for decentralised rural development and governance. *Blockchain-Research and Applications*, *3*(3). https://doi.org/10.1016/j.bcra.2022.100086

Move to Fundão. (2024). *Fundão em números*. https://movetofundao2024.pt/

Nagariya, R., Mukherjee, S., Baral, M. M., Patel, B. S., & Venkataiah, C. (2022). The Challenges of Blockchain Technology Adoption in the Agro-based Industries. *International Journal of Mathematical Engineering and Management Sciences*, *7*(6), 949–963. https://doi.org/10.33889/IJMEMS.2022.7.6.059

Nakamoto, S. (2008). *Bitcoin: A Peer-to-Peer Electronic Cash System*. www.bitcoin.org

Nunziante, E. (2025). How the EU Data Strategy Can Foster the Growth of Agri-tech Market. *Journal of Law, Market and Innovation*, *4*(1), 33–62. https://doi.org/10.13135/2785-7867/11805

OECD. (2019). *The Path to Becoming a Data-Driven Public Sector* (OECD Digital Government Studies). OECD. https://doi.org/10.1787/059814a7-en

Panwar, A., Khari, M., Misra, S., & Sugandh, U. (2023). Blockchain in Agriculture to Ensure Trust, Effectiveness, and Traceability from Farm Fields to Groceries. *Future Internet*, *15*(12). https://doi.org/10.3390/fi15120404

PORDATA. (2024). *População residente, saldo migratório e variação demográfica – Município do Fundão*. Fundação Francisco Manuel Dos Santos. https://retratos.pordata.pt/populacao/fundao

Rajchandar, K., Shameem, A., Biswas, P., Geetha, B. T., Arunkumar, J. R., & Lakineni, P. K. (2023). Supply Chain Management Using Blockchain: Opportunities, Challenges, and Future Directions. *Proceedings of 2023 2nd International Conference on Informatics Ici 2023*. https://doi.org/10.1109/ICI60088.2023.10421633

Rocha, G. da S. R., Mühl, D. D., Chingamba, H. A., de Oliveira, L., & Talamini, E. (2023). Blockchain, Quo Vadis? Recent Changes in Perspectives on the Application of Technology in Agribusiness. *Future Internet*, *15*(1). https://doi.org/10.3390/fi15010038

Rodrigues, M., & Franco, M. (2021). Digital entrepreneurship in local government: Case study in Municipality of Fundão, Portugal. *Sustainable Cities and Society*, *73*. https://doi.org/10.1016/j.scs.2021.103115

Schiefer, G. (2019). Anticipated Futures for Modern Rural Economies - a Request for Guidance by Research, Policy and the Business Community. *International Journal on Food System Dynamics*, *10*(4), 396–401. https://doi.org/10.18461/IJFSD.V10I4.27

Sekuloska, J. D., & Erceg, A. (2022). Blockchain Technology toward Creating a Smart Local Food Supply Chain. *Computers*, *11*(6). https://doi.org/10.3390/computers11060095

Silveira, F., Silva, S. L. C., Machado, F. M., Barbedo, J. G. A., & Amaral, F. G. (2023). Farmers' perception of barriers that difficult the implementation of agriculture 4.0. *Agricultural Systems*, *208*. https://doi.org/10.1016/j.agsy.2023.103656

Sridhar, A., Ponnuchamy, M., Kumar, P. S., Kapoor, A., Nguyen Vo, D. V., & Rangasamy, G. (2023). Digitalization of the agro-food sector for achieving sustainable development goals: a review. In *Sustainable Food Technology* (Vol. 1, Issue 6, pp. 783–802). Royal Society of Chemistry. https://doi.org/10.1039/d3fb00124e

Sukhetska, K., Novak, I., Movchaniuk, A., Gomeniuk, M., & Pitel, N. (2025). Blockchain Technologies as a Driver of Transformation in the Agricultural Sector. *Agricultural And Resource Economics-International Scientific E-Journal*, *11*(3), 165–193. https://doi.org/10.51599/are.2025.11.03.06

URBACT. (2023). *Innovation, talent attraction and social inclusion in Fundão*. URBACT Programme. https://urbact.eu/good-practices/innovation-friendly-city?utm_source=chatgpt.com

Vern, P., Panghal, A., Mor, R. S., Kumar, V., & Sarwar, D. (2025). Unlocking the potential: leveraging blockchain technology for agri-food supply chain performance and sustainability. *International Journal of Logistics Management*, *36*(2), 474–500. https://doi.org/10.1108/IJLM-09-2023-0364