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Environmental challenges and innovative responses of local agri-food systems: a theoretical approach

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Abstract

Purpose – This paper aims to analyse how local agri-food systems (LAFS), compared to other production models, can offer innovative responses to the important environmental challenges facing food production under the twin transition. These responses are more conducive to community inclusion and local development.

Design/methodology/approach – The paper combines territorial development, clusters and industrial districts literature with studies on agri-food industry environmental problems and twin transition technologies to develop an agri-food systems typology. This typology is based on a territorial approach to environmental challenges of food production and serves to illustrate the ways in which LAFS can provide innovative responses to these challenges.

Findings – The study allows to visualise the differences between LAFS and other agri-food production models, showing how the operationalisation and implementation of digitisation occur at territorial level and how rural communities are involved in the process. The theoretical proposal emphasises not assuming that technology is inherently beneficial but ensuring that its implementation is inclusive and generates social value for the communities.

Originality/value – The paper aims to enrich future research by adopting a territorial perspective to study the twin transition challenges associated with food production systems.

Keywords Local agri-food system, Twin transition, Environmental challenges, Territorial agglomeration

Paper type Conceptual paper

1. Introduction

Food production systems face significant environmental challenges as both agricultural production and agri-food industries generate significant harmful effects on air, soil, water

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and biodiversity. These effects are probably greater than those of any other human activity (Tyler, 2006). Indeed, there is a consensus in the literature on the need for transformations in agri-food systems to achieve more sustainable forms of production. This article studies these transformations from a territorial perspective, analysing local agri-food systems (LAFS), examining their environmental challenges and describing what kind of innovative responses these systems can offer to face these challenges.

The literature on territorial development has extensively studied how local productive systems, such as industrial districts or clusters, have faced important challenges associated with global competition, crises or shocks worldwide (e.g. Becattini, 2004). These studies have emphasised local development experiences to promote innovative responses considering territorial specificities. In this paper, we adhere to this approach by considering local development theories to enhance the understanding of how territories can respond to current food production environmental challenges. To this end, we propose a theoretical framework that combines three strands of literature that, in general, have advanced separately, without enough dialogue between them.

The first strand of literature focuses on territorial development, cluster and industrial districts, with a special emphasis on the agri-food industry. In particular, we build on the LAFS approach, which adopts the general principles of industrial districts and innovative *milieus* to study local food production systems (see Section 2). The second strand of literature draws on studies on the environmental problems associated with the agri-food industry from the perspective of environmental, ecological economics and industrial ecology (Section 3). Finally, the third strand of literature characterises agri-food system innovations with a particular interest in the interplay of twin transition (digital and green) technologies (Section 4).

Based on the intersection between these three streams of literature, this article proposes a typology of agri-food production systems considering the environmental challenges they face, the level of interaction between actors and the degree of territorial agglomeration (Section 5). Within this conceptual framework, the article analyses the potential of LAFS compared to other models of agri-food production to generate innovations in response to environmental challenges under twin transition. Finally, we offer some conclusions and suggest an agenda for future research on the topic (Section 6).

2. Main features of local agri-food systems

The study of LAFS emerged as an extension of theoretical frameworks from local production systems (e.g. industrial districts and clusters) to the agricultural production and agro-industry sectors (Iacoponi, 1990; Rodríguez-Cohard and Parras, 2011). In particular, the term LAFS was coined in studies on small and medium-sized agri-food enterprises in Africa (López and Muchnik, 1997) and agro-industries in Latin America (Boucher and Muchnik, 1998).

LAFS are geographical concentration of firms processing agricultural and livestock products, which constitute the core of the agri-food industry (Santa María and Giner Pérez, 2017). Apart from core firms, LAFS functioning relies on rural producers, companies supplying inputs for production (such as fertilisers and chemicals or machinery), providers of different services (e.g. financial services, distribution, technical and business management, quality control and marketing) and public and private support organisations (training centres, universities, technology centres, rural producer associations or business chambers). Building on the general principles of industrial districts (Becattini, 2004) and innovative *milieus* (Camagni and Maillat, 2006), LAFS approach considers that productive organisation is the result of the interaction of people, companies, organisations, local knowledge, social capital and networks, within a specific institutional and historical framework and on a particular spatial scale (Muchnik and Sautier, 1998; Rodríguez-Cohard and Parras, 2011; Sforzi and Mancini, 2012). In the same way, Muchnik *et al.* (2008) argue that the LAFS approach considers the relationships between the human being, the product and the territory, for which the concern of territorial specificities and local culture is fundamental.

The foregoing requires analysing the specificities of the local population, its institutions, the products and production processes and the local culture, particularly, the consumer food culture. LAFS approach stresses that networks foster trust and access to information and innovation, insofar as they facilitate healthy competition and cooperation (Poméon and Fraire, 2011). Furthermore, the institutional framework and support organisations constitute the basis for these systems' formal and informal governance (Giacomini and Mancini, 2015).

However, despite the several similarities between LAFS and other territorial production systems, there is a fundamental aspect of agri-food industries that differentiates them from the rest of industries: in agri-food production, firms tend to locate with greater dispersion in the territory, conditioned by the spatial allocation of natural resources and raw materials. While spatial proximity is essential to facilitate the exchange of ideas and the diffusion of innovations (Phillips *et al.*, 2013), a LAFS is not necessarily one continuous geographically bounded space (Muchnik *et al.*, 2008; Santa María and Giner Pérez, 2017). According to Giacomini and Mancini (2015), a LAFS can be a reference area that is neither small nor spatially perfectly continuous, but still constitutes a single entity based on a sense of belonging and sharing common interests (Bonnemaison *et al.*, 1999). Given that production activities are often spread over different areas, LAFS are a result of organisational proximity and their "localness" is provided by inter-firm cooperation and participation in social networks (Giacomini and Mancini, 2015). The greater territorial dispersion of LAFS implies that, within them, diverse local environments in terms of institutional factors, human capital endowment and agri-food local industries can coexist, giving rise to different competitive and collaborative strategies (Galaso and Rodríguez Miranda, 2022).

Therefore, assuming that agglomeration in rural spaces differs from agglomeration in urban spaces (which distinguishes LAFS from other local production systems), the LAFS model still requires that at least agricultural producers maintain a certain degree of agglomeration in a delimited territory. Yet, as noted above, industrial activities do not necessarily have to be agglomerated in a given territory. Hence, a LAFS can take two forms:

(1) based on the primary production component without incorporating the local presence of industries; and

(2) based on both rural producers and food industries that make up a network embedded in a specific territory.

Since LAFS advocate for local, sustainably produced products, they can not only enhance a rural development strategy, but also contribute to goals in the protection of biodiversity, environmental resources and rural culture through promoting strategies that take advantage of local capacities for adaptation and innovation. Moreover, LAFS can constitute important tools to facilitate the intervention in the territory of government and development organisations and the coordination with extra-territorial actors for achieving a favourable insertion in local markets (Poméon and Fraire, 2011). In addition, in the value chains of the food industry, there is a permanent tension between the value and the specificity of the local and global dimension. In this tension, the relational dimension plays a key role, expressed in the different networks (local, national and global) and the place and role of each actor. According to Sforzi and Mancini (2012), LAFS could give rise to a strategy of "global network of places", where each LAFS could specialise in a different component of the agri-food system. However, the articulation of socio-territorial development projects with the interests of global production networks is an open and complex challenge.

In summary, based on the above ideas, we can consider that LAFS differ from other (non-localised) agri-food production models essentially because of two factors:

(1) the actors involved form an intensely connected network; and

(2) at least the agricultural producers present a certain degree of territorial agglomeration.

In the following sections, we will see how these two factors determine both the environmental challenges and the potential of LAFS to offer innovative solutions under the twin transition.

3. Environmental challenges of agri-food systems

Like all primary activities, agriculture is closely linked to using natural resources (National Research Council, 2015) and ecosystem services (Swinton *et al.*, 2007; Elmqvist and Maltby, 2010). Ecosystem services is the term used to refer to the benefits derived from natural resources for human activity, determining the values that they place on ecosystems (Costanza *et al.*, 1997; Wallace, 2007).

The primary natural resource, directly used in production, is soil and the necessary land use. The occupation of land for food production affects biodiversity and CO_2 emissions when land-use changes affect carbon stock (Hermansen and Nguyen, 2012) or absorption. Water is another significant input for agriculture and livestock production. In fact, agriculture is the largest single user, accounting for around 75% of human water use (Wallace, 2000, FAO, 2017). Besides soil and water, other production and regulating ecosystem services are in food production (Elmqvist and Maltby, 2010). In addition to renewable natural resources and ecosystem services, agriculture has incorporated other external inputs to increase productivity, transforming it into an increasingly intensive activity. Agriculture has introduced modern or high-yielding crop varieties (Evenson and Gollin, 2003) and intensified the use of agrochemical and biotechnological inputs, energy and capital goods (Griffin, 1990; Binswanger, 1986; Pingali, 2007). This intensification in the use of natural resources, inputs, energy and capital has led to a significant increase in productivity and the reduction of natural uncertainties.

However, this intensification in modern agriculture has also led to a more significant impact of agriculture on the environment (Gear, 1994; National Research Council, 2015), with significant harmful effects on air, soil, water and biodiversity, probably greater than any human activity (Tyler, 2006). It has also reduced food production's renewability and energy efficiency (Gear, 1994).

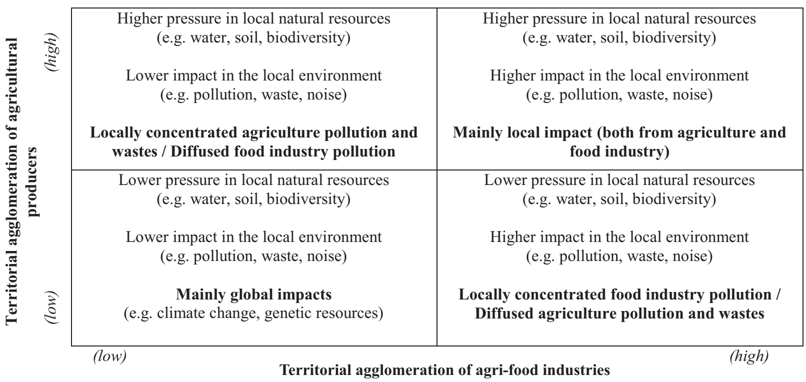
Increasing use of resources and intensification in agricultural activity affect environment and, hence, human welfare and other economic activities. The primary sector traditionally competes with other human activities for the use of resources, for example, industrial areas, infrastructures or urban development generates pressure on specific areas where agricultural or livestock farming activities are carried out (Gardner, 1977; Smith *et al.*, 2010). A similar situation occurs with water when industry and urban uses compete with the agri-food system for this increasingly scarce resource (Strzepek and Boehlert, 2010; Pereira, 2017).

Not only primary activities, but also the activities of the food industry, a key player in agri-food systems, have a direct impact on the environment. Firstly, the food industry intensifies the use of energy during the transformation of agricultural products, especially in the processes that involve heating and refrigeration (Walshe, 1994), which is added to consumption during distribution and transport, especially when it is done refrigerated (Dellino and Hazle, 1994). Secondly, agro-industry has a direct impact on environment through their intensive use of water in transformation processes (Wheatley, 1994) (conditioning raw material, processing and cleaning machinery or facilities). Thirdly, agro-industry causes noise pollution and odours (Walsh and Key, 1994) due to the use of machinery and equipment, especially for compression and refrigeration. Finally, the impact derived from food packaging to provide product protection, communication and utility (Selke, 1994) that increases the quantity, type and complexity of the materials used by the agri-food industry.

Given the differences between agricultural and industrial activities in their interaction with the environment, we propose to incorporate a territorial approach distinguishing between two essential dimensions of agri-food systems: the agglomeration of agricultural activities and the agglomeration of food industries. In Figure 1, we use these two dimensions to develop a typology of environmental challenges.

The greater agglomeration and specialisation of agricultural activity would increase pressure on the territory's natural resources (land, water and biodiversity) and agricultural pollution. In the same way, the greater agglomeration of the agri-food industry also favours more significant impacts on the local environment, mainly in terms of pollution, noise and wastes. When both agriculture and industries are territorially agglomerated, they tend to compete for the same resources, especially water and land. They could also be generators of the same types of pollution and waste, thus, increasing the concentration of environmental pressures and local impacts. If the agri-food industry is dispersed, it reduces its impact on the local environment, being agriculture agglomeration the central origin of environmental pressures. Concentration of agricultural activity would demand the same typology of land, with appropriate characteristics for the specific primary production, have similar water requirements (i.e. with the same irrigation periods) and/or use identical chemical inputs (fertilisers, pesticides, etc.), increasing the local concentrations. Oppositely, the dispersion of agricultural activity would reduce the pressure on local resources (land, water and biodiversity) and agricultural contamination would be fundamentally diffuse. In this case, the concentration of the agri-food industry (imagine the case of specialised agro-industrial districts) would be the primary source of environmental pressures, for example with intense local demand for water and high generation of wastes and pollution. When both agricultural and agri-food production are widely dispersed in the territory pressures on local resources decrease and impacts on the environment are mainly on a global scale (i.e. climate change, genetic resources or global biodiversity).

The typology displayed in Figure 1 can be further nuanced, as the nature and intensity of environmental impacts are contingent upon the specific type of production and are



Source: Own elaboration

Figure 1. Environmental pressures and impacts of agricultural and agri-food industry by degree of agglomeration

influenced by the proactive measures undertaken by producers and industries for prevention and mitigation. However, it is evident that for the same type of production, technique and technology, including those of an environmental nature, the agglomeration of agricultural and/or industrial production intensifies local environmental impacts.

4. Innovations to environmental challenges in agri-food systems under twin transition

Due to the impact of climate change, the protection of biodiversity and the recent COVID-19 crisis in food supply chains, international organisations and academics have recognised the crucial role of innovation in the transformation of the agri-food sector to achieve greater efficiency, sustainability, inclusion and resilience (FAO, 2022a; Barrett *et al.*, 2020; WEF and FAO, 2022). Digitalisation, linked to the emergence of Fourth Industrial Revolution technologies, and sustainability, related to the adoption of circular models and decarbonisation schemes by economies, are two interconnected dimensions that play a crucial role in agri-food transformation. In this context, an extensive literature highlights the positive contribution of digital technologies – broadly conceived as an evolution of the technological revolution led by information and communication technologies that fusion in a wide variety of technological domains (Menéndez *et al.*, 2023) – to achieve more sustainable processes of production and consumption (Mäkitie *et al.*, 2023). However, significant research gaps persist regarding the systemic effects of both technologies on the environment (Mouthaan *et al.*, 2023) and "profit-driven nature" of innovations making it hard to be self-aligned with sustainability purposes (Béné, 2022).

To provide insight into the role of digital technologies, current FAO's science, technology and innovation strategy claims that agri-food systems transformations require a broad set of innovations "[including digital], social, policy, financial, and institutional)" (FAO, 2022a, p. 7). Among the digital, artificial intelligence (AI), drones, robotics, sensors and global navigation satellite systems stand out for precision, decision and efficiency within agro-industrial context (FAO, 2022b). For instance, within the domain of soil and water management, on-the-ground and remote sensing controls how much to irrigate based on predictive models and efficient AI-based applications (Brunori, 2022). Similarly, these technologies can early detect damages by water pests and agrochemicals (FAO, 2022b). In addition, a report from FAO (2022b) points out that, within agriculture, automated control of mechanised systems (driverless tractors, harvest robots) controls crops. These technologies extend further; encompassing cattle supervision such as electronic tagging adopts to monitor cattle health, alongside milking robots and automatic feeders for cattle management. In addition, e-commerce and the platform economy impact farm and supply chain management engendering novel relationships between producers and between producers and consumers.

Herrero *et al.* (2020) shed light on innovations by categorising them into 10 groups of food system technologies: cellular agriculture, digital agriculture (e.g.: advanced sensors, AI, big data, among others), food processing and safety, gene technology, health, inputs, intensification, replacement food/feed, resource use efficiency and other technologies (e.g.: 3D printing, battery technologies, among others). These groups of technologies can be analysed considering their position in the value chain (production, processing, packaging, distribution, consumption and waste) and their technological maturity. For example, digital agriculture is associated with a relatively large number of mature technologies due to the speed of innovation and lower costs of digital technologies. However, authors claim that the simultaneous adaptation of these technologies and the resulting transformation of food in each country or region will depend on their socio-economic context, as well as the presence of institutional and political constraints. In short, innovations *per se* are not enough to transform agri-food systems, as it requires a bundle of complementary technological innovations, policies, knowledge, social institutions and cultural norms for ensuring broad stakeholder participation while reducing trade-offs across multiple objectives and achieving broad-scale results (Barrett *et al.*, 2020). Moreover, WEF and FAO (2022) argue that successful agri-food transformation at national and regional levels requires an inclusive and holistic approach to innovation. This approach prioritises interoperability and sufficient digital infrastructure to enable collaboration, maintain informed farmer agricultural production and encourage consumer participation (WEF and FAO, 2022, p. 5).

The previously reviewed conceptualisations – to a greater or lesser extent – highlight the interaction between innovations and the spatial context. The territorial concentration/dispersion of agricultural producers and the agri-food industries poses different environmental challenges (see Figure 1 above), the magnitude of which depends on the digital sustainable innovative responses those producers and industry adopt aimed at addressing these challenges. The research on innovative solutions to environmental issues facing territorial agri-food systems is still scarce. A study focused on the EU, pioneer region in promoting a green and digital development strategy, has identified limited prospects for economic development in agricultural regions in the twin transition due to low innovation potential, poor accessibility, lacks of skills, lower investment and high intensities of CO_2 emissions (Maucorps *et al.*, 2022). In this regard, we identify two technological paths related to the environmental pressures and impacts of LAFS based on the level of dispersion/agglomeration among agriculture producers and the agri-food industries.

On the one hand, big food corporations have the power in the global value chain and dominate agri-food systems putting a special pressure on local natural resources and on local environment. According to Clapp (2021), in very concentrated sectors, the innovation pathway focuses on very high-tech technologies and very high cost proprietary technologies (biotechnology) capital intensive rather than on innovations more accessible such as agro-ecology. Within this digitalisation megatrends, this form of market concentration means that companies have established leadership positions in emerging digital platforms for agriculture and computer-aided genome editing. For Béné (2022), virtuous processes of innovation might be interrupted due to the protection of their assets and investments and generating process of lock-in in unsustainable trajectories, like for the case of red meat (McGreevy *et al.*, 2022). The responses towards environmental challenges through adopting digital technologies might not have the expected results in terms of sustainability. Concentration of database digital technologies in big corporations might generate problems in food systems by restrictions on farmer's choices and limitations for novel start-ups to access data (IPES-Food, 2017).

On the other hand, juxtaposed with the prominent presence of big food corporations, agri-food sector is characterised by the prevalence of small farms that account for one-third of the world's food production. Moreover, they exert a key role in maintaining the crops and livestock genetic diversity as well as in supporting ecosystem services. Therefore, innovations and market institutions are essential for bolstering agro-ecological diversity within various socio-economic contexts, particularly in low and middle-income countries (Diao *et al.*, 2023). Tailored innovations targeting specific environmental challenges appear to be the best response. In this regard, digital innovation responses aimed at promoting sustainability that requires strong availability, inclusivity, accessibility and adaptability within the local, regional and national contexts. This entails direct engagement and participation in the work process of non-codified knowledge transfer that traditionally takes place among farmers (FAO, 2022a, 2022b; HLPE, 2019). Only in this way is it possible for innovative responses to reach a wide range of potential beneficiaries and, thus, avoid widening technological gaps that disadvantage vulnerable groups and remote territories (FAO, 2022b).

As it is pointed out by Herrero *et al.* (2020), "the digitalization of agriculture and some other technologies could provide ample opportunities to spread and scale transformative solutions" (p. 271). For instance, several innovative responses to environmental challenges can be applied in rural areas, such as the "Disembodied digital solutions" that are software-based solutions that require limited hardware, like a smartphone or a tablet, however, data availability is not enough to generate tailored actions to specific local conditions required by small-scale producers (FAO, 2022b). One of the main limitations to adopt these technologies is the lack of digital infrastructure in rural areas, digital skills and an inadequate legislation on data privacy reducing the possibilities for inserting in a virtuous path of digitalisation for sustainability.

5. A typology of agri-food systems according to their environmental challenges

Building upon the three streams of literature discussed in the previous sections, we now provide a typology of agri-food systems according to their environmental challenges and opportunities for innovative responses within the framework of twin transition. To do so, we rely on the two dimensions proposed in Section 3 (agglomeration of agricultural activities and agglomeration of food industry). As shown in Figure 2, this allows us to study the two LAFS models in comparison with other (non-localised) models of agri-food production.

Let us begin explaining the upper right part of the figure: an agri-food production system where both agricultural producers and industries are territorially agglomerated. To the extent that these co-localised actors form a strongly interconnected network, they constitute a LAFS. The literature has documented several examples of this type of LAFS, such as wine, dairy and oil industries (Rodríguez-Cohard and Parras, 2011; Maghssudipour *et al.*, 2020; Galaso and Rodríguez Miranda, 2022). In these cases, not only primary production is strongly anchored to the territory, to its environmental, economic, cultural and institutional conditions, but also, industrial activities that process the agricultural raw material (e.g. milk, grapes or olives). Essentially, two types of reasons can explain the agglomeration of industrial activities in this type of agri-food system. Firstly, as a matter of efficiency, the

Territorial agglomeration of agricultural producers (low → high)

Territorial agglomeration of agricultural producers	(low) Territorial agglomeration of agrifood industries	(high)
(high)	**LAFS BASED ON PRIMARY ACTIVITIES** **Environmental challenge:** Locally concentrated agriculture pollution and wastes **Response:** Potentially systemic and adapted to local capabilities and needs (less potential if innovation is driven by industry not located within the LAFS).	**LAFS BASED ON PRIMARY AND INDUSTRIAL ACTIVITIES** **Environmental challenge:** Local impact combined from agriculture and food industry **Response:** Potentially systemic and tailored to local capabilities and needs.
(low)	**NATIONAL AGRI-FOOD SECTOR** **Environmental challenge:** Mainly global impacts **Response:** Global solutions linked to multinational corporations based on high technology, capital-intensive and proprietary rights.	**INDUSTRIAL AGRI-FOOD CLUSTER** **Environmental challenge**: Locally concentrated food industry pollution and wastes **Response:** Potentially systemic and tailored to the needs of the industrial cluster, not necessarily to the conditions of the rural producers and their local environments.

Source: Own elaboration

Figure 2. Typology of agri-food systems according to their environmental challenges

production process may require that industrial activities be located close to primary production. Secondly, historical trajectories occurring in certain regions may lead to a specific productive culture integrating all phases of the production chain within the same territory. As explained in Section 3, the agglomeration of both agriculture and industry implies environmental challenges associated with the pressure on natural resources and the impact on the local environment. Therefore, innovation led by agricultural producers and industries that are located in a given territory and interconnected in a collaboration network provides the opportunity for systemic solutions to emerge. These solutions are not only focused on the impact of the industry or primary production, but also take a comprehensive and tailored approach to local conditions, needs and capabilities.

The typology located in the upper left part of Figure 2 does not involve the agglomeration of industrial activities. In this case, agricultural producers are placed within a shared region (which is geographically and culturally defined) and interconnected in a network of relationships centred on primary production. In this model, local agricultural producers sell to industries located outside the LAFS, which operate on a national scale or respond to global value chains led by multinational corporations. In these cases, a large part of the industrial activity (e.g. packaging and food processing factories) can be located in distant territories. Therefore, this typology can be referred to as agricultural (and not industrial) LAFS. In this type of LAFS, the environmental challenges will be associated with the pressure on natural resources exerted by agricultural activities. The response to these challenges may take advantage of the territorial vision of agricultural producers. However, the potential for systemic innovation, which considers the interaction between agriculture and industry at the territorial scale, will be more difficult than in the first LAFS model, since industries are external to the territory and their innovative responses may respond to different interests that may not be in line with environmental impacts at the local scale.

Figure 2 presents other agri-food production systems that cannot be considered LAFS. In the lower left quadrant, there are systems where there is no type of territorial agglomeration, neither of agricultural nor of industrial activities. These are the national agri-food sectors, whose stakeholders may form a network with a clear sectoral focus on agri-food production, but with hardly any territorial agglomeration. These national networks could be part of global networks and be under control of few big players (typically subsidiaries of multinational corporations). In this case, the environmental challenges are on a global scale. As a result, the innovative response also focuses on global solutions associated with multinational corporations' challenges, based on high-tech technology, capital-intensive practices and proprietary rights. In other words, innovations take place under the control of a few powerful players with high barriers to entry that are likely to exclude a substantial portion of small and medium producers, while leaving issues related to local impacts unaddressed.

Finally, in the lower right quadrant, we can find models where only industry is agglomerated but there is no territorial agglomeration of agricultural activities. This production model may be analogous to an industrial cluster that uses raw materials coming from agriculture to produce food, but the interaction between agriculture and industry is not connected to the territory, so we cannot consider it LAFS. In this case, there are incentives for tailored solutions to emerge based on the needs of the industrial cluster. However, this does not necessarily address the environmental challenges faced by the producers and their local environment.

In summary, Figure 2 offers a framework to analyse to what extent the interplay of digital-green technologies not only addresses the problems of feeding the growing world population in an environmentally sustainable way but also considers how to promote (or not undermine) the conditions of economic and social development of the territories, rural communities and small producers. In turn, innovation processes for a twin transition in agri-food systems should consider the inclusion of small producers and address local problems of pollution and environmental degradation. This cannot be addressed from de-territorialised global or national perspectives. Even solutions to environmentally global challenges require initiatives supported by local producers and citizens, to be truly sustainable from a comprehensive perspective (social, economic and environmental).

6. Conclusions

In this article, we have analysed the environmental challenges of agri-food systems and their innovative responses from a territorial perspective. In this sense, we have proposed a typology that considers how, depending on network interaction and territorial agglomeration, agri-food systems face different environmental challenges that also entail different responses under the twin transition.

In the case of non-LAFS models (i.e. national agri-food sectors and industrial agri-food clusters), there is a lower likelihood of undergoing digitisation processes towards a sustainable transformation (Agri-food 4.0) that considers the specificities of rural communities and small producers. For instance, in industrial agri-food clusters, solutions might be focused on the needs of the industrial sector and then applied to the primary phase, which may not fully account for the reality of rural producers and their local environments. In national agri-food networks, innovations might be tailored by multinational corporations in which global solutions are imported not considering the specific needs and conditions of each territory.

The latter does not prevent us from recognising that large multinational companies are concerned about integrating Industry 4.0 in food production to meet the growing global demand in an environmentally sustainable manner. As Abbate *et al.* (2023) show, multinational companies have shifted towards prioritising long-term gains over short-term profits, emphasising strategies to create shared value and mechanisms of control through digital technologies in agricultural activities and their impact on natural resources. In the same line, Lezoche *et al.* (2020) argue that integrating Industry 4.0 into the agri-food industry (achieving an Agri-food 4.0) aims to support better decision-making throughout the supply chain and enable more efficient, data-driven decisions at the farm level. This improved management can lead to greater economic efficiency within a framework of sustainable soil, water and carbon emissions management. However, the question arises as to whether these solutions are adapted to local contexts and allow the inclusion of small farmers in these more sustainable and efficient models. Instead, these solutions are driven by top-down logic through global value chains, rather than emerging from local experiences tailored to the specificities of territories.

In the case of LAFS, the likelihood of considering the needs of local communities and producers is much higher. This is not guaranteed, but there is a greater potential for innovative responses that are adapted to the local reality and capabilities. For example, the operationalisation and implementation of digital technologies and how rural communities are involved in the process is a key aspect for ensuring that its implementation is inclusive and generates social value for the communities (Bellon-Maurel *et al.*, 2022). In addition, territory and the local networks of actors are relevant in the digitalisation of agriculture. In this regard, promoting collaborative platforms, encouraging place-based initiatives, and fostering open innovation among various local and regional actors for the implementation of Industry 4.0 in agriculture facilitates the development of distinct strategies in different regions according to their problems, challenges, and networks (Hervas-Oliver *et al.*, 2021). This approach can be likened to the opportunities that a production model associated with a LAFS can generate, in contrast to other models that lack territorial embeddedness.

Finally, the role of public policy is crucial in achieving a sustainable and inclusive digital transformation for agri-food systems. LAFS have significant potential for developing an inclusive and sustainable digital transformation tailored to local needs and capabilities. However, the presence or absence of the agri-food industry in the territory where food is produced and the type of actor leading the value chain in which production is integrated – SMEs, large national companies or multinational corporations – is also a relevant factor. In this context, public policy can play a pivotal role in unlocking the potential that a LAFS can offer, which is not assured by its mere existence.

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