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A collaborative and multidisciplinary approach to knowledge-based rural development: 25 years of the PSDR program in France

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ABSTRACT

The uneven rural development and the investigation of the place of rural areas in the modern knowledge-based economy raise an important question. How can we foster knowledge emergence and dissemination in peripheral areas that are often considered less innovative due to their remoteness and weak technological creativity? This paper aims to present the contributions of the French PSDR program to rural knowledge creation and dissemination in France based on a comprehensive and synthetic analysis of its participatory research projects. We identify five key components of the knowledge-related PSDR approaches which have significantly contributed to rural innovation in France linked to (1) the governance of agricultural lands, (2) the territorial attractiveness and well-being, (3) the agroecological transition in the territories, (4) the territorialized food systems, as well as (5) the bioeconomy and circular economy. We emphasize the need to combine technological, organizational, and territorial innovation and involve local partners in the design and elaboration of research programs. Rural areas can thus produce new knowledge beneficial to local communities and transferable to other sectors or territories. Finally, we suggest a comprehensive territorial vision for knowledge-based rural development and discuss the importance of a national multidisciplinary and participatory research program.

1. Introduction

The place of rural areas in national socio-economic development remained uncertain for a long time. Rural development policies differed widely over time and from one country to another, emphasizing agricultural activities, industrialization, or services to the local population (Torre and Wallet, 2020). Rural territories have recently been increasingly recognized as crucial, particularly in industrialized countries, for not only agricultural production but also recreational spaces, biodiversity preservation, natural areas, and local culture (Kim et al., 2005; Torre and Wallet, 2016). Based on this multifunctionality, rural livelihood diversification contributes to meeting the needs of city dwellers and in-migrant rural households with an urban lifestyle and provides transition pathways for rural sustainability (Smith and Phillips, 2001; Wilson, 2010). It has become necessary to implement diversified rural policies that consider the specific characteristics and resilience of local territories (Westlund and Kobayashi, 2013; Pelucha et al., 2021). In other words, policymakers should explore smart rural development based on knowledge and innovation (Naldi et al., 2015).

However, there are several limitations to rural innovation and knowledge development. The concept of a Knowledge Economy has been debated and studied for decades (Westlund, 2006). A large body of work highlights innovations in large urban areas (Grandadam et al., 2013; Secundo et al., 2020). Rural areas are deemed much less well-off and suffer from an insufficient innovation capacity because of a lack of knowledge suppliers, educational institutions, and adequate education among local actors (Bock, 2016). The small population size and its sparse distribution over the rural territories also lead to a certain level of disconnection and weak network connectivity (Fountain et al., 2021).

Many researchers criticize the above remarks as a typical but incomplete conception of the knowledge society which focuses mainly on formal, academic knowledge and technological innovation (Rooney et al., 2005; Neumeier, 2012). An essential part of rural knowledge relies on grounded know-how and networks of local actors with different objectives and goals from those in metropolises. Knowledge is less formal and more experiential in rural areas, where innovations are more rooted in the social and institutional fabric; the knowledge imported from outside is reinterpreted and reformulated to adapt to local realities (Li et al., 2016; Šūmane et al., 2018). Therefore, on the one hand, it is always important to introduce to rural territories the most recent

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progress in science and technology, such as digital technologies or electrical mechanization (Cowie et al., 2020). On the other hand, public policy and actions need to support the emergence and development of local knowledge embedded in rural products, e.g., labeled local products or the Protected Designation of Origin (Cañada and Vázquez, 2005), and practices and skills of the rural population, e.g., the short supply chains (de Roest et al., 2018).

The work on the Knowledge Economy for regional and rural development has increased extensively in recent years, focusing on innovative milieus (Crevoisier, 2004), learning regions (Asheim, 2012), and other approaches to contribute to rural sustainability and resilience (Li et al., 2019). These approaches emphasize social innovation, local knowledge, and networks between local and external actors (Cooke, 2005; Neumeier, 2017; Jones et al., 2021). There is a strong demand for cross-boundary research across sectors and scales (Eversole, 2021) to encourage collective learning through formal and informal knowledge interactions (Tödtling et al., 2006) and to support the development of innovation clusters (Varis et al., 2014). However, several major problems need further consideration. For example, most previous research was about innovation in firms and industries or knowledge-based entrepreneurship in rural areas (Richter, 2019; Kristensen and Dubois, 2021). A systemic vision is needed considering agriculture (Arzeni et al., 2021), food system (Martindale, 2021), forestry (Weiss et al., 2021), rural living standards (Jacobs et al., 2019), and other broad themes. There are still not many empirical reports about how knowledge-based initiatives are developed in the territories, what initiatives can facilitate the involvement of regional authorities and other partners, how the policy adapts to new urban-rural relationships, etc.

The experiences developed in the PSDR program ("For and On Regional Development") in France can hopefully provide meaningful responses to these questions. The program financed multiple research projects from its first generation, launched in 1996, to PSDR4, which closed in 2020. All projects followed several principles, such as solid interaction between regional partners and research institutes, co-definition of research themes, multi- and inter-disciplinary approaches, collaborative and participatory research between researchers and non-academic actors, and linkage with multi-level rural networks (Box 1). These research projects covered broad themes linked to agriculture, forestry, food, agroecological transition, and other issues in rural and peri-urban areas. The idea of the program is to enhance local techniques, introduce and adapt external knowledge, and, above all, encourage the emergence and development of local expertise, knowledge, and tools that territorial actors and other rural areas can use..

The objective of the paper is to present an overview of the PSDR approach during the last 25 years and the main findings of the projects for knowledge-based rural development and resilience. The goal is twofold: first, to present the new knowledge they bring to French rural territories regarding agricultural land governance and other issues; and second, to explain how this knowledge is locally created or reinvented based on local skills, cooperation between stakeholders, and the exploration of existing innovations. The structure of the paper is as follows. Section 2 is a literature review on rural development in the knowledge economy and an introduction to the PSDR approach. Section 3 presents the main results of the PSDR program in its most recent generation around five critical issues of rural knowledge and innovation. Section 4 discusses the contributions of a participatory and comprehensive

Box 1
A short introduction to the PSDR Program in France

The PSDR ("For and On Regional Development") program (www.psdr.fr) was first launched in 1996 and recently closed its 4th phase in 2020 (Table 1). Its first generation - DADP (1996–1998) - established the basic principles of the program, including 1) Strong interaction between regional partners (e.g., the Regional Councils of participating regions) and research institutes (especially INRAE, the French National Institute for Agriculture, Food and Environment) in co-funding the projects and defining research themes; 2) Special attention to territorial development processes in rural and peri-urban areas directly or indirectly linked to agriculture, forestry, food, and other agroecological issues; 3) Collaborative research in partnership with local actors throughout all stages of the projects; 4) Research projects rooted in territories and interdisciplinary approaches combining social and natural sciences.

Each generation improved the strategy and approach of project management. For example, all projects were coordinated by a researcher-actor pair after the first experimentation carried out in DADP2 (2001–2005). All projects participated in one or more of the three joint working groups formally created in PSDR4 (2014–2020), following tentative initiatives in PSDR3 (2007–2011) to strengthen collaboration between projects. PSDR3 reinforced the requirement for improving the quantity and quality of scientific publications from the projects, with an independent national jury in charge of evaluating the projects and their results. There was also a shift in focus from knowledge dissemination to facilitating reuse from DADP2. The projects had extra funding for one year dedicated to knowledge transfer supported by a communications team at the program level in PSDR4. A book chapter about PSDR3 explained how the projects were selected and managed (Torre and Wallet, 2022).

An increasing number of regions participated in the program, starting with those of specialty crops and services and followed by those of industrial field crops. The focus of the projects also extended beyond agricultural production to a wide variety of topics contributing to sustainable regional development, for example, food systems, value chains, farmland management, urban-rural relationships, natural resources, environment, climate change, territorial impacts assessment, and public policy. The research outline evolved to address the rising societal demand for agroecological transformation, food quality, circular economy, and the coordination of different goals. Many projects worked, stimulated by the reform of the Common Agricultural Policy (CAP) and the successive versions of the Green Deal, on the search for alternative agricultural systems and social structures to ensure a balance between agricultural, environmental, climate, and smart rural development objectives. The program aimed to contribute effectively to regional and territorial development by providing information, methods, and tools for local actors' decision-making and action, particularly within the framework of regional policy priorities.

In PSDR4, the 33 projects mobilized 128 research teams (universities, institutes, …), combining various disciplines of social sciences and natural sciences with an average of 4 teams per project. About 151 non-academic partner organizations were involved (on average 5 per project), including actors from the agricultural world, local and territorial authorities, decentralized services of the State, environmental organizations, industrial and service companies, fishing and forestry stakeholders, and others. There were more than 1100 participants, of which 73% were researchers.

The TETRAE program ("Transition in Territories of Agriculture, Food and Environment", 2022–2027) succeeds the PSDR and retains the same structure and principles. TETRAE aims to promote transitions toward more sustainable territorial development. It revolves around three essential points: reasserting the central place of local territories in sustainable development, opening up the research towards the socio-economic world and civil society, and focusing on transitions under the Agriculture – Food – Environment – Health nexus.

Table 1
A brief overview of the PSDR Program's past four generations.

Program generations	Number of projects	Number of participating regions[a]	Budget	Key progress in strategy and approach
DADP (1996–1998)	21	3	No data	Establishment of basic principles (i.e., partnership with regional councils, collaborative research, interdisciplinarity)
DADP2 (2001–2005)	76	5	€ 6 M	Experimentation of project coordination by a researcher-actor pair; a shift in focus from knowledge dissemination to facilitating reuse
PSDR3 (2007–2011)	36	10	€ 10 M	Increasing requirement for scientific results of projects; experimentation of joint working groups; external evaluation by an international jury
PSDR4 (2014–2020)	33	14	€ 11 M	One extra year for knowledge transfer; creation of a communications team at the program level

[a] Regions before the French territorial reform effective on January 1, 2016.

research program like PSDR to rural innovation compared with other relevant initiatives in order to provide some general and critical thinking for future research and policy-making. Section 5 concludes the paper and opens ways for the future.

2. Knowledge-based rural development: a theoretical review and the PSDR problem-driven approach

This section presents a literature review on rural development challenges and the research and policy for a knowledge-based rural economy, followed by a conceptual introduction of the problem-driven approach of the PSDR program. This summarization of the PSDR approach aims to provide a tool that bridges the gaps in rural development between top-down knowledge and local innovation and between researchers and actors.

2.1. Literature review

2.1.1. Challenges of rural development

In the background of globalization and the growing mobility of capital and people, it has been widely noticed that rural areas are often marginalized in socio-economic development (Bock, 2016; De Toni et al., 2021). Many are experiencing population decline and a downfall in private business, employment, and public services. The reasons are associated with the geographical and relational remoteness of rural areas due to limited socio-economic connections. The lack of knowledge institutions and links to them results in weak innovation systems in peripheral regions, demonstrating a low level of collective learning and insufficient capacity to absorb interregional knowledge spillover (Pelkonen and Nieminen, 2016). It is worth noting that initiatives increasing the connectivity of these remote areas without improving local innovation capacity may lead to the risk of resource-grabbing and rural gentrification (Zoomers, 2022).

Several large-scale studies of the European Territorial Observatory Network (ESPON) show the need to consider territorial disparity, diversity, and balance in rural research and policy-making. The EDORA findings highlight the different capacities at the micro-scale to respond to the "ubiquitous drivers" of rural change (Copus et al., 2011). The PROFECY final report shows a spatial variation between two main drivers of inner peripherality: a lack of access to regional centers and services and poor economic potential (Noguera et al., 2017). The ESCAPE results suggest a diverse shrinking pattern and substantial intra-regional variation (Copus et al., 2020). The authors remind us that many European regions are declining due to relative disadvantage rather than absolute weakness compared with nearby regions.

Rural areas need to meet the rising societal demands, especially from urban citizens, for high-quality food, a circular economy, labeled local products, natural environment, and other services. The regulation of the CAP and the EU Green Deal has reinforced the requirement for agro-ecological transition and more sustainable development pathways. Rural resilience is no longer essentially linked to the agriculture sector but a question combining the environmental, territorial, and socio-economic dimensions (Pelucha et al., 2021). Rural research needs to adapt to societal and policy needs. It remains a big challenge to coordinate multiple development goals and explore alternative agri-food systems. Therefore, the transformation resilience of rural areas becomes the key to preventing system crises (Dwyer, 2022). When "business as usual" becomes impossible, the capacity of a rural territory to change its internal structure and feedback mechanisms toward a new healthy, dynamic, and efficient system will be crucial.

France faces these general challenges and some specific characteristics. The share of the agriculture sector in employment and the economy has diminished considerably. However, the role of agricultural activities remains essential in spatial planning and landscape management. France has experienced a significant evolution towards regional specialization in agriculture and rural economy (Chatellier and Gaigné, 2012). Agri-food industrialization and exportation characterize the North-West and, to a lesser extent, the South-West parts. The North-East part relies more on an industrial tradition. In the South-East, on the contrary, specialty agricultural products and services contribute most to the local economy, e.g., labeled products, short supply chains, rural tourism, and second homes (Le Bras and Schmitt, 2020). Remote rural areas generally see a shrinking and aging population, but rural attractiveness tends to increase in the metropolitan outskirts and coastal areas under intense land pressure. As in the case of PSDR (Box 1), the regions of specialty agriculture were the first motivated to search for alternative production models and value chains. Those dominated by large-scale industrial crops and livestock are increasingly urged to break the socio-technical lock-in favoring intensive farming (Meynard et al., 2018) by the rising demands for agroecological transition, sustainability, and resilience. These territorial specificities of France call for heterogeneous research focus in cohesion with the regional context and multi-level coordination to facilitate exchange and collaboration among projects. The research outline and strategy of the PSDR program (Section 2.2) considered these specificities and relevant needs.

2.1.2. Research and policy for a knowledge-based rural development

The creation and exploitation of knowledge have become the predominant engine in developing wealth and progress in the knowledge economy and society (Peters, 2010). Previous research has revealed the following critical elements of knowledge-based rural development.

First, apart from technological innovation, social and cultural innovation is also essential in rural areas (Dargan and Shucksmith, 2008). There can be divergent pathways for knowledge transfer and collective learning through formal and informal knowledge interactions (Tödtling et al., 2006; Slee and Polman, 2021). Kristensen and Dubois (2021) propose a framework combining the function of social ties (e.g., bonding, bridging, and linking) to achieve organizational proximity in order to construct a rural cluster. Torre et al. (2020) suggest a regional strategy to focus on diversity and related variety in rural areas to facilitate inter-sector knowledge spillover and borrow size from more developed neighboring regions.

Second, rural innovation is steered from the bottom up and driven by local communities and initiatives (De Toni et al., 2021; Zoomers, 2022).

It means identifying local needs and integrating local knowledge, strengths, and opportunities (Bosworth et al., 2016; Arzeni et al., 2021; Kluvankova et al., 2021). Thus, there should be a new perspective of governance connecting global and grassroots efforts (Leach et al., 2012; Eversole, 2021). Pelkonen and Nieminen (2016) suggest relying on existing networks and local resources to solve the problem of lacking dynamic clusters or knowledge suppliers in rural areas.

Third, the over-reliance on the local network may reduce creativity (Varis et al., 2014). It is crucial to improve the "absorptive capacity" of the territory and individuals to exploit external knowledge (Cohen and Levinthal, 1990). Cooperation between local and external actors at regional or sub-regional levels is necessary (Dahlström and James, 2012).

At the policy level, rural development has become the 2nd Pillar of the EU's Common Agricultural Policy since Agenda 2000. A menu of measures is proposed to the Member States or regions to design Rural Development Programmes (RDP). Some have explicitly targeted to support knowledge transfer and innovation since 2007 (Bonfiglio et al., 2017). The CAP is in continuous reform, and one central issue is reinforcing its contributions to regional growth and cohesion. The task remains challenging because the CAP is criticized as a cause of increasing territorial imbalance (Esposti, 2011; Bonfiglio et al., 2017). The RDP 2007–2013 integrated LEADER initiatives, a bottom-up method in the EU to reinforce the "links between actions for the development of the rural economy". Social innovation and networking are of central importance (Dax et al., 2016; Georgios et al., 2021). The integration into RDP has largely brought the small-scale and limited-budget LEADER program to the mainstream, though it is now showing a gradual decline (Georgios et al., 2021). At least 5% of RDP funding must go to actions based on Community-led Local Development (CLLD-LEADER). The EU regulations 2021/2115 for CAP Strategic Plans 2023–2027 reaffirm the importance of Agricultural Knowledge and Innovation Systems (AKIS) and locally led initiatives like LEADER.

The successive shifts of European regional development policies over the programming periods have underlined the difficulty in reconciling competitiveness and cohesion. Innovation, R&D, and other intangible factors have been emphasized as the engine of economic growth since the 1990s. The support for smart specialization and place-based initiatives for a decade tried to counter the harmful effects of the "wholesale" and one-size-fits-all approach centered on advanced technologies. However, existing strategies did not sufficiently consider territorial specificities, the role of infra-regional dynamics, and the quality of governance and intermediation systems at these scales. This defect calls for a reinforcement of knowledge production and dissemination mechanisms that stick more closely to the contemporary issues of rurality.

Policy evolution impacts the focus of the research (as mentioned in Box 1, Section 2.1.1) and, in turn, is influenced by the research, e.g., the assessment of territorial imbalance and the conception of social innovation mentioned above. Nowadays, huge amounts of data, reports, videos, etc., of the European Commission and the EU-funded research projects, e.g., Framework Programs, ESPON, and RURAGRI ERA-NET, are available on the websites. Thus, research can be closer to operational actors and provide them with case studies, development models, action points, databases, and networks. In France, research has successfully brought a territorial dimension to rural development policy by revealing the impacts of the territorial context on the performance of governance mechanisms. Researchers have also drawn the attention of policymakers to stakeholder diversity and the development of consultation tools promoting collaboration and learning dynamics. In addition, considering territorial configurations justifies place-based policies, which integrate the particularities of rural territories (Torre et al., 2020).

2.1.3. Major problems and needs for knowledge-based rural development

The above review leads to the identification of several major problems for knowledge-based rural development nowadays, which needs to:

i) be based on a systemic vision addressing a variety of subjects and their interdependence in rural areas, e.g., agriculture, food, ecological transition, rural well-being, adaptation, and resilience under the changing urban-rural relations.
ii) reconcile the targets of local territories and regional development in defining research themes and implementing projects. This reconciliation is essential for binding together different stakeholders and obtaining resources at regional and supra-regional scales.
iii) involve researchers and actors in different disciplines to address broad issues (Lowe and Phillipson, 2006).
iv) develop collaborative research and bridge the gaps between research institutions (knowledge suppliers) and other actors in rural areas to promote territorial innovation (Doloreux et al., 2019).
v) integrate informal and formal knowledge from local and external actors to avoid the risk of reduced creativity in an isolated system. Rural communities need to connect to global pipelines, which are trans-local knowledge linkages between regions and clusters (Morrison et al., 2013).

2.2. The PSDR approach

The work and results of the PSDR program can provide helpful solutions that respond to the needs presented in Section 2.1.3. The program was designed based on several principles, which became increasingly evident over subsequent generations (Box 1). These principles, aiming to produce scientifically rigorous knowledge directly useable by local partners or policymakers, can be grouped into five broad categories. Fig. 1 presents how these principles potentially respond to the problems and needs in knowledge-based rural development.

2.2.1. Broad research themes for rural areas

The projects in the PSDR program covered the major themes related to rural development, which facilitates a systemic vision in public action addressing new challenges to rural territories. The research themes were defined following regional needs and the demand of the EU's new Cohesion Policy, Smart Growth priority under Europe 2020, and the new CAP for the transition of agriculture and rural areas in the context of climate change.

These research themes can be summarized into five categories: 1) governance of agricultural lands under increasing pressure in rural and peri-urban areas; 2) territorial attractiveness and well-being, including landscape preservation, cohesion, and competitiveness between regions and territories; 3) agroecological transition in the territories in light of local conditions and global changes, such as the evolution of agricultural practices and adaptation to climate change; 4) territorialized food systems in pursuit of food security, social benefits, and environmental sustainability; 5) bioeconomy and circular economy. Researchers and partners also participated in three joint working groups among projects to promote knowledge exchange between regions and produce general and transferable results and tools. These joint working groups focused respectively on: rural-urban relations around land use, attractiveness, and well-being, agroecological transition in different systems and territories, and innovation to boost circularity in the food and forestry systems and chains.

2.2.2. Strong interactions between research organizations and regional partners

Within the framework of the general topics selected at the national level, local research teams worked with policy and decision-makers to define the specific research subjects in each region. This smart development strategy is highly grounded in local problems and needs. Local teams first conducted some preliminary diagnostics about, for example, the depopulation processes in mountain areas, the agroecological

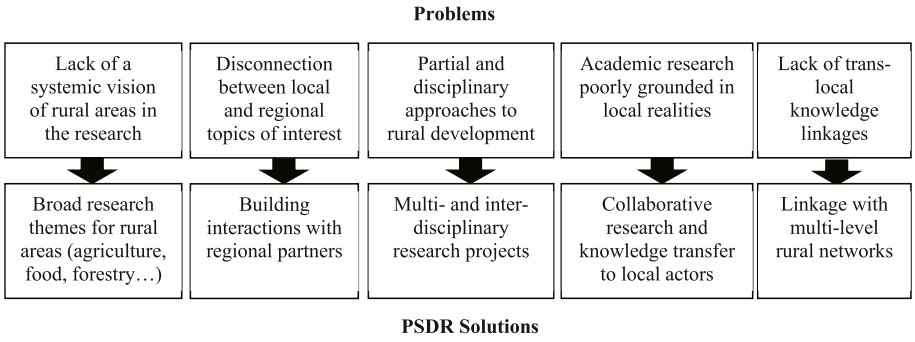

Fig. 1. The PSDR solutions to the problems in knowledge-based rural development (Source: Authors' original work).

transition through the development of pulse crops, and the short supply chains near the capital city of the region.

The Regional Council provided at least 50% of the project funding. They followed their projects' progress with the coordinators of the PSDR program and participated in a regional monitoring and consultant committee. They expect to integrate the knowledge produced in the projects into regional policy-making.

2.2.3. *Multi- and inter-disciplinary research projects*

A partial or disciplinary approach can hardly meet the requirements of a global and systemic vision of the problems at the territorial level. PSDR research projects are interdisciplinary at two levels:

Recommended by the evaluation bodies of the program, the projects were proposed and carried out by multidisciplinary research teams. The general design and all work packages should include multidisciplinary research. For example, none of the projects had a purely economic or agronomic work package, and most projects engaged teams from social and natural sciences.

The projects in PSDR4 involved about 40 disciplines, including 10 in social sciences and 30 in natural sciences. The most frequent disciplines included economics, sociology, geography, agronomy, ecology, management, politics, and law.

2.2.4. *Collaborative research and knowledge transfer to local actors*

Each PSDR project was coordinated by a researcher and a non-academic partner and based on collaboration between research teams and local partners in defining research topics, theoretical framework, fieldwork, and the transfer of results. The 151 partners involved in the program included agricultural actors (e.g., cooperatives, groups of farmers, and the chambers of agriculture), local authorities (e.g., municipalities or groups of municipalities, department councils, and regional councils), decentralized bodies of the State for research, agriculture, and environment activities, territorial organizations (e.g., "Pays"), water agencies, Regional Natural Parks, and other actors in territorial development (e.g., environmental organizations, industrial and service companies, and fishing and forestry stakeholders).

The fifth year of PSDR4 was specifically dedicated to transforming scientific results into practical tools to promote knowledge transfer to local actors and other regions. The PSDR projects created about 1000 operational products, including thematic meetings and workshops, training courses for students, professionals, and the public, videos, e-books, manuals, software, databases, posters, etc. These products include good practice manuals for actors and territorial expertise guides to help local decision-makers select and elaborate public action. Most of them have been shared on social media and are freely available on the web.

2.2.5. *Linkage with multi-level rural networks*

The PSDR program is close to the European Innovation Partnership for Agriculture (EIP-AGRI)[1] in principles and structure, which has enabled their cooperation in the Rhône-Alpes region. The EIP-AGRI initiative comprises multi-stakeholder projects searching for practical and concrete solutions to a problem or an opportunity. It aims to facilitate the transfer of innovation and knowledge between countries in order to foster agroecological transition across Europe. The PSDR projects in the Rhône-Alpes region were also involved in the French Collective Mobilization for Rural Development (MCDR)[2] program to support collaborative projects with a national or inter-regional dimension, promote network building, and contribute to rural development.

This joint coordination between the three initiatives in the projects has brought about fruitful results. Primarily, it indicates an approach for rural areas to create knowledge linkages with multiple rural networks across local, regional, national, and European levels. Teams with different targets worked jointly to organize workshops and produce practical documents sharing the results of innovative projects with various actors and policymakers. These partnerships echo the multi-level perspective on transitions (Geels, 2002). The production of practical knowledge favoring agroecology or short food supply chains has contributed to operational standards and strengthened their legitimacy in public policies and stakeholder strategies.

3. Results of the PSDR4 projects about rural knowledge and innovation linked to agriculture and food issues

The research of the PSDR projects in very different local territories leads to essential contributions to understanding the dynamic evolution and resilience of rural spaces and concrete proposals for public action. This section presents the key findings of the recently closed PSDR4 projects linked to five major issues in rural development among the broad research themes introduced in section 2.2.1. References to publications from the projects are provided in the text.

3.1. *Governance of agricultural lands*

Multiple PSDR4 projects studied the resilience of farming systems near the city, where agricultural lands face increasing urban pressures. They focused mainly on adaptation strategies and land management that help peri-urban farming to persist. The multidisciplinary PSDR approach facilitates a systemic vision combining research on land use management, social relations, and agroecological impacts, which contributes to identifying new opportunities and trade-offs in agricultural land

[1] The EIP-AGRI is supported by the EU's Common Agricultural Policy (the European Agricultural Fund for Rural Development) and the European research and innovation program Horizon 2020.

[2] The MCDR program is coordinated by the National Rural Network of France.

governance under urban pressure.

First, land use studies reveal the difficulty of making land available for agricultural activities at the urban-rural interface. For example, downzoning from an urban development zone to an agricultural zone in land use planning means a loss of value for landowners and could lead to litigation in the administrative court (Le Bivic and Melot, 2020). However, researchers have identified innovative practices of land ownership backing ("portage foncier") to help new farmers to get land for cultivation through the transfer of land use rights and diversified design of innovative agricultural projects (Léger-Bosch et al., 2020). One of the projects has created an interactive digital tool to manage local land resources for agricultural projects. It is an open web platform of collaborative mapping for local actors to report property initiatives.

Then, the research on social relations suggests recognizing the importance of local agriculture at the urban-rural interface following the change in eating habits and lifestyles in cities. For example, home gardens in metropolitan outskirts significantly contribute to the diet of working-class households, but their value has long been underestimated (Darly et al., 2021). Farmland preservation in peri-urban areas can be integrated with local food strategies, which enables to rethink of the meaning and ways of sustainable urban planning (Buyck et al., 2021; Kassis et al., 2021). In addition to farmers and other traditional actors, local municipalities, residents, and social services are increasingly engaged in agricultural and food issues. The relationship between society and agriculture is now growingly influenced by consumers and public authorities with rising interest in local food.

Other research on the ecological impacts of land use changes shows that the urban-rural interface, valley bottoms, and agricultural/industrial wastelands favor the production of ecosystem services and the preservation of biodiversity. These lands are conducive to agroecological transition. Researchers find that peri-urban areas with intermediate proportions of urban and agricultural lands (Renaud et al., 2022) and urban domestic gardens (Levé et al., 2019) positively impact pollination and plant species richness. However, water contamination in peri-urban areas is more correlated with agricultural fertilizer and pesticides than urban land use. Thus, public policy should consider the environmental risk linked to agricultural activities (Nélieu et al., 2021). These findings can provide pathways for change in public policies on biodiversity. Some foresight workshops between local institutional actors and other stakeholders have mobilized these results using a specific method AVEC® to draw "future landscapes" for interface areas like urban and peri-urban farmlands.

3.2. Attractiveness and well-being of the territories

The attractiveness of rural territories represents a significant issue in the public action of European countries in the last decades with increasing consideration of the well-being dimension. PSDR projects have developed a comprehensive approach to assessing territorial attractiveness. They investigate the basis for individual and collective well-being in a territory and how the two are articulated with each other and with territorial attractiveness. The well-being indicators and the surveys among local populations have made it possible to demonstrate the advantages of rural territories in terms of attractiveness.

For example, Bourdeau-Lepage and Fujiki (2021) surveyed local people's perceptions of their living environment. They identified the key territorial components of well-being in rural areas, e.g., natural amenities, access to health services, and safety. They highlight that the decision-makers must consider the objective and subjective dimensions and the individual and collective dimensions of public policies and strategies. Tardieu and Tuffery (2019) show that, besides socio-demographic characteristics, the biophysical context plays a prominent role in the recreational attractiveness of the territory and should also be considered in the recreation policy and planning. They claim that GIS-based mapping can be a valuable tool for valuing landscape services in people's daily decision-making. These results and tools help to develop participatory strategies to optimize well-being, renew landscape design, and contribute to public policies for improving territorial attractiveness.

3.3. Agroecological transition in the territories

PSDR projects conceive agroecological transition as the change of agricultural models to promote sustainable food systems that respect people's benefits and their environment, both at the farm and territorial level (Charpentier et al., 2019; Magrini et al., 2019). This approach combines technical and agronomic research and the mobilization of supporting services, consumers, and various other actors in local territories to improve farmers' knowledge and involvement (Bouttes et al., 2018). The results show that, besides addressing the question "what is good in a biophysical sense", considering local actors' perception and participation is highly meaningful to the target of agroecological transition.

The work on biophysical dimensions shows that considering potential ecosystem services is a major lever of agroecological transition at all scales: regional, territorial, or farming systems (Lopes et al., 2017; Fauvel et al., 2020). Many technical manuals have been developed to help farmers and agricultural advisers to understand the benefits of biodiversity to agriculture. PSDR teams investigated the autonomy of the farming systems, including cultivation, breeding, and the re-composition of the two. They have developed alternative systems that reconcile animal welfare with the health of the system at the farm and territorial levels while reducing dependence on synthetic inputs (Forteau et al., 2020; Guinet et al., 2020a, 2020b; Maxin et al., 2020; Mugnier et al., 2021). Practical guides have been created to facilitate the construction of nitrogen-autonomous systems with farmers through design and conception workshops and the diagnosis of nitrogen losses in the fields.

Another big part of the work was about the involvement and cooperation of local actors in the transition processes, especially in sharing knowledge, learning, and accompanying projects. The results call to rethink the role of agricultural advisors in providing technical support for a systemic change, which needs to adapt to the singularity of the projects and local situations and develop knowledge for and with local actors (Catalogna et al., 2018). Several practical tools of PSDR projects help different actors to understand the transition practices. For example, the Agroecology Dictionary is an online and evolving multimedia tool providing definitions of the main terms and concepts in agroecology. The Capflor® software is a digital decision support tool for grassland design. Other tools include multiple synthesis booklets on the conversion to organic agriculture, a video game around the practice of mixed breeds, etc.

3.4. Territorialized food systems

The PSDR4 work suggests a three-level approach combining conception, governance, and collective intelligence to territorialized food systems.

For the conception, researchers have revealed different forms of innovation that redefine the links between food, agriculture, and territory (Galliano et al., 2019). The work shows differentiated dynamics of reterritorialization in the production, transformation, and distribution of food value chains (Desquilbet et al., 2018; Madelrieux et al., 2018). This reconnection of agriculture, food supply, and people in local territories brings long-term benefits. It helps to define the trajectories of the Territorial Food Projects[3] by combining individual and collective contributions.

PSDR results also show the importance of governance associated

[3] The Territorial Food Projects were introduced by the French Law for the Future of Agriculture, Food, and Forestry (LAAF) of 2014.

with these systems. Local elected officials and public actors play an essential role in structuring sustainable food systems through multiple levers such as collective catering, land management, or support for local agriculture (Magrini et al., 2019; Kassis et al., 2021). However, launching local food strategies beyond the modest and scattered initiatives is challenging. Civil society can be a remarkable driving force through collective and individual practices, e.g., food self-production and diet change for the sake of human and animal health (Monier-Dilhan, 2018; Duru, 2019; Morel-Journel et al., 2021). The economic operators in charge of processing, distribution, and others still have a marginal place in food governance, though they can strongly influence the creation of territorial food systems.

In the end, the research shows a strong need for accompanying instruments and collective intelligence, which allow actors to rethink and implement changes in their territory. In this respect, the PSDR collaborative research projects, emphasizing the joint work between stakeholders, consultants, and research teams, have developed multiple tools promoting skills and knowledge learning, such as algorithms, chronicles, games, and good practice guides.

3.5. Territorial bioeconomy and circular economy

Unlike the traditional linear production processes, the secondary products or wastes are partly reused or recycled in the form of material or energy flows in the circular economy and bioeconomy. PSDR results underline the territorial dimension of the bioeconomy (Vivien et al., 2019). Several projects worked on the deployment of local loops related to food issues and other agricultural and forestry activities. The production reterritorialization and the activation of territorial resources help to create an innovation ecosystem conducive to territorial resilience and local network creation.

These PSDR projects observe an active development of a circular economy in agriculture in France, especially the anaerobic digestion projects (Bourdin et al., 2020) and territory-based initiatives for improving circularities in forestry (Fortin et al., 2019; Bessaad and Korboulewsky, 2020; Lenglet and Peyrache-Gadeau, 2021). These studies reveal the adaptation strategies of enterprises and cooperatives. They also demonstrate the acceptability of residents and other actors and the creation process of innovative eco-projects in rural areas. The results show that localization is a recurrent argument of circular economy projects for two main reasons. First, it allows a more environmentally friendly and economically efficient local loop than the long-distance transport of products and energy flows. Second, it calls for collaboration with different stakeholders in the territories, which reinforces territorial governance. It is important to consult not only the actors engaged in the bioeconomy projects but also the local population, who are sometimes opposed to certain initiatives, to ensure their agreement (Bourdin and Nadou, 2020; Niang et al., 2021).

4. Discussion: implications for knowledge-based rural development and limitations

In a rural context marked by fewer actors in the innovation ecosystem, collaborative research projects like those in the PSDR program can be intermediaries promoting knowledge co-production and transfer. They also contribute to the structuring of research communities, involving permanent actors who go beyond the framework and periods of the program.

4.1. Toward a territorial vision of knowledge-based rural development

The PSDR approach underlines the importance of territorial innovation for knowledge-based rural development. It means to combine innovation processes connected with a given territory, in which actors organize themselves to develop new knowledge. As seen from the evolution of the CAP (Section 2.1.2), rural development is no longer considered merely an agricultural or a sectoral issue. The research and policy-making ask for strengthening a territorial vision. The PSDR program, just as its full name suggests (Box 1), emphasizes addressing territorial needs, focusing on territorial processes, and working with various related actors. The approach contributes to a comprehensive conception of a territorial vision for rural development, which should be multiscale, collaborative, and multidisciplinary. This multiscale vision allows it to combine top-down and bottom-up initiatives, integrate local and regional interests, actors, and resources, and connect internal and external networks. The collaborative approach facilitates research out of laboratories, focusing on problems and solutions close to the territory. Multi- and interdisciplinary work is necessary to successfully address territorial problems, which are usually complex and multifaceted. Multidisciplinary projects may find new opportunities and trade-offs by making visible the relationship between agriculture, society, environmental issues, food security, and other subjects, as the examples in Section 3.1 show.

The PSDR results have confirmed previous observations that most innovation processes in rural areas are in social, cultural, and organizational dimensions (Hargrave and Van de Ven, 2006; Le Chevalier, 2019; Moulaert and Maccallum, 2019). Technological innovation, which always matters, is probably less central and often imported and adapted from outside of rural areas. Innovation is growing faster in rural territories because digital technologies are increasingly frequent at all stages of agricultural value chains (Cowie et al., 2020). More importantly, local projects foster innovations in terms of short supply chains, land use management, and circular economy, which have improved the well-being of local communities. The PSDR results on agroecological transition demonstrate how the collective dynamics of actors (especially the groups of farmers), who are confronted with common problems associated with a specific territorial context, facilitate the generation of appropriate knowledge and more sustainable solutions. This idea about territorial innovation is consistent with social metabolism in addressing transition issues, which requires considering the entire flow of materials and energy needed to sustain all human activities (Fischer-Kowalski and Haberl, 2015).

4.2. Significance of a national research program like PSDR in the creation of a multidisciplinary and participatory community for rural knowledge and innovation

The PSDR experiences suggest the significance of a national program of its type in creating and maintaining a huge participatory community at the national level for rural knowledge and innovation. This community integrates a variety of research teams, practical actors, policymakers, and other partners and goes beyond the framework and periods of the program. The PSDR program was the first initiative in France of its type. The connection within the PSDR community has a multi-level structure. First, local research teams and actors cooperate closely within a project focusing on specific topics and problems of that territory. Second, the regional committee and project management team actively facilitate exchanges between projects in the same region. Third, the three joint working groups (Section 2.2.1) and the seminars, participatory workshops, and other scientific events organized at the program level promote knowledge exchange and cooperation at the national level.

The PSDR community kept growing over the past generations and became quite stably embedded and well-known in the territories. For example, some research projects carried out continuous social experimentation in PSDR3 and PSDR4. Local actors and research teams have become more familiar with the participatory research approach, methods, and joint territorial learning process. This working mode and associated cooperation network continue to exist in the next TETRAE, other research programs, and many policy initiatives. One example is the integration of the PSDR in the Rhône-Alpes region into the EIP-AGRI initiative (Section 2.2.5).

Thus, a national multidisciplinary and collaborative research program can make significant contributions to addressing rural challenges beyond the single project level. The active work of a multi-level coordination team has promoted effective knowledge exchange and cooperation between social and natural sciences and different territories. The intense national coordination can be a peculiarity of the PSDR program compared to other relevant European initiatives, e.g., the EU Framework Programs (European Commission, 2019), Horizon 2020, and ERA-Net RURAGRI. The national level is in proximity to the regions compared to the EU level, which makes the national level ideal for performing certain functions in territorial development and fostering knowledge and practice exchanges.

4.3. Limitations and future perspectives

The PSDR program shows the advantages of a multidisciplinary and collaborative approach, which mobilizes multiple research teams and local actors to produce new knowledge in favor of the evolution of perceptions and practices. But this type of project requires cognitive resources to translate local issues into research questions and transform scientific progress into practical tools. It also requires substantial human and financial resources because the project needs the regular presence of non-academic actors, which is sometimes difficult, especially for those strongly based on voluntary work. As the example of PSDR shows, the non-academic participants are usually the head of their organization, which call into question the potential for disseminating new knowledge to end-users. Another problem is the weak participation of civil society. Associations remain relatively few among PSDR partners. The participating associations are institutionalized representations of citizens and are sometimes far away from the local population. It is thus difficult for local people to have their opinions heard. The future design of collaborative research programs should consider these limitations.

Future programs must also pay attention to the complexity of regional development. The CAP measures (Bonfiglio et al., 2017) and the Cohesion Policy (Berkowitz et al., 2015) have shown their limits in responding to the challenges of territorial imbalances. In this regard, future research and policy should recognize the spatial effects of knowledge-based territorial actions and networks. Can they bring solutions promoting cohesion between different regions, or do they aggravate inequalities? To what extent do they contribute to reconsidering rural-urban relations in the knowledge economy? The existing research often neglected the territorial dimension of transitions, and there is a call for a spatial perspective in transition studies (Coenen et al., 2012).

A territorial vision of transitions is central to the objective of INRAE in transforming the PSDR into the TETRAE program. The future program deploys the systemic interdependencies between different fields (agriculture, food, environment, health, waste management, land use, etc.) and the tensions and potential collaborations between stakeholders. It will lead to the experimentation of solutions based on open innovation and the confrontation of expertise to identify new territorial configurations that foster mutually beneficial relationships between urban and rural areas. A further limitation that the future program will address is a reflection on social, cultural, and psychological barriers to agroecological transition and changes in production and consumption patterns of agri-food systems. It is important to analyze why the initiatives for change often need long-term involvement and can hardly be successful in the short term.

5. Conclusion

The paper presents the contribution of the PSDR program to collaborative knowledge creation and open innovation in rural territories of the vast majority of French regions for more than 25 years. The analysis of the program's basic principles and the main results obtained by the projects allows us to draw three main conclusions: i) the results are very rich and diverse, primarily related to the governance of agricultural lands, the territorial attractiveness and well-being, the agro-ecological transition in the territories, the territorialized food systems, as well as bioeconomy and circular economy; ii) the collaboration initiated from the outset of the projects between researchers and local partners is essential for a shared definition of research themes and collaboration between consortium members; iii) the funding specifically devoted to the transformation of results to scientific and practical products at the end of the projects is an essential condition for the success of the program.

The PSDR approach contributes to a comprehensive territorial vision for knowledge-based rural development. Yet there are several limitations. The PSDR program requires the substantial involvement of project coordinators at different levels, which is challenging to maintain over the long term without significant financial support. Moreover, the non-academic partners are mainly from the private, public, or associative sectors without the real involvement of civil society. These results question the relevance of the quintuple helix model (Carayannis and Campbell, 2010) applied to contexts outside dense and high-tech urban spaces. Thus, the PSDR experiences underline that future participatory research needs to create conditions for the long-term involvement of field-based actors, including civil society, in innovative projects and promote knowledge dissemination beyond partners. Finally, future research should also pay attention to the complex spatial impacts of the territorialized rural initiatives and the transition of agriculture and rural areas at the request of the new CAP, the EU Green Deal, and the changing urban-rural relationships.

Credit author statement

André Torre: Conceptualization, Methodology, Formal analysis, Writing-original draft, Writing-review and editing, Validation, Supervision, Funding acquisition. **Frédéric Wallet:** Methodology, Formal analysis, Writing-original draft, Writing-review and editing, Validation, Project administration. **Jiao Huang:** Methodology, Formal analysis, Data curation, Writing-original draft, Writing-review and editing, Validation.

Data availability

No data was used for the research described in the article.

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