Eco-innovations towards circular economy: evidence from cases studies of collective methanization in France

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Abstract

Facilitating the circulation of resources and knowledge in territories is a key dimension in the transition to a circular economy. The purpose of this article is to identify the factors and dynamics of development of circularity at meso-economic level through the study of the eco-innovations on which it is based. We study collective methanisation projects in the South-West of France. We use a mixed method, "quantified narrative method" to characterize the development process of the projects via the nature of the resources mobilized and how they have been acquired. The analysis of the 167 resources mobilised highlights technological and organisational eco-innovation dynamics that support the development of circular economy in rural areas. Our results confirm the role of three eco-innovation factors: local resources, sectoral and institutional environments, i.e. place-based and extra-local factors. They also highlight the importance and interdependence of local and regional networks of project leaders, institutional actors and market actors. The construction of circularity results in exchanges between the agricultural and energy sectors, which intensify throughout the projects, thus reinforcing the effects of related variety. However, this circularity remains incomplete and could be reinforced through public policies designed to help these projects gain a stronger foothold.

Keywords: eco-innovation, anaerobic digestion, resources, networks, rural, methanisation

Introduction

The circular economy (CE) is the establishment of an economy that minimizes the loss of materials and energy to preserve the biosphere and the resources it provides (Geissdoerfer et al., 2017). This non-linear economy is based on the creation of loops, circular systems, in which the waste generated by one process becomes the raw material for another. To do so, actors have to shift beyond strictly sectoral concerns and consider the territorial dimension in their strategies (op. cit.). This development of circularities rests on both technical and organizational innovations whose inter-sectoral and localized nature thus deserves examination. What types of resources and relationships foster innovations that contribute to reinforce localized processes of CE? Although the literature linking CE and eco-innovation is growing (de Jesus & Mendonça, 2018; Cainelli et al., 2020; Vence & Pereira, 2019), it still pays little attention to the factors that promote the development of these innovations or to their actual effects on the construction of circularity.

This article, therefore, aims to define the factors and dynamics of development of circularity through the study of the eco-innovations on which it is based. Thus, we aim to answer the following question: what are the scales and dynamics of resource mobilization and circulation that promote innovation towards circular economy practices?

The originality of our study is threefold. In terms of object, the CE is the focus of a growing number of studies in which issues related to coordination between activities receive increasing attention. However, agricultural and agri-food activities are seldom the focus of analysis (Gallaud & Laperche, 2016). And yet, the agricultural sector is recognised as playing a key ecological role, particularly through the use of biomass (Duque-Acevedo et al., 2020). Moreover, rural areas, in which most agricultural activities are located, are given little consideration in studies on the CE. From a theoretical point of view, we refer to the literature on innovation economics and more specifically on environmental innovation to analyse the development of CE initiatives. Recent literature supports the idea that eco-innovation is a key point in the transition toward CE (de Jesus & Mendonça, 2018 ; Vence & Pereira, 2019). The spatial dimension is little examined, except in studies about networks that emerge in more or less localized CE or industrial ecology initiatives (Taddeo et al., 2017; Boons & Howard-Grenville, 2009). And when it is, it often refers to urban and industrialized territorial contexts, neglecting the rural dimension of CE. Finally, we conducted our field surveys using an original methodology developed in economic sociology - *quantified narratives* – that helps to reveal the dynamics of embeddedness vs. decoupling of innovation processes, both from a geographical and relational point of view (Grossetti, 2011). This method serves to analyse, at the different phases of project construction, the resources used by the actors but also how they are acquired. We apply this method to an aspect of the CE that is little studied by scholars in the social sciences: the exploitation of biomass through collective methanisation projects involving both farming and non-farming stakeholders[1] located in the same territory. The case of collective projects also relates to original territorial contexts in which the issue of natural resources and the low concentration of economic activities can potentially hinder circularity processes.

The article is organized into four sections. The first introduces our theoretical framework, which is based on a spatial approach of the literature on eco-innovation and CE. The second describes the Quantified Narrative methodology and the case studies. We then present and discuss the results we have obtained concerning the structure and dynamic of the projects through qualitative and statistical analyses. The last section provides conclusions and presents the implications of the findings in terms of policy.

1. Theoretical framework

1.1.The circular economy and environmental innovation

The concept of CE recently emerged in national and European public debates but it has its origins in past research, particularly in industrial ecology and ecological economics (Korhonen et al., 2018). It is based on the realization of the unsustainability of the current economic system that fails to take into account the characteristics of ecological systems. This concept promotes a systemic approach to economic activity, and highlights the need to move towards "a regenerative system in which resource input and waste, emission, and energy leakage are minimised by slowing, closing, and narrowing material and energy loops" (Geissdoerfer et al., 2017, p. 766). The creation of material and energy loops can be achieved through a wide variety of actions that refers to the "3R" process (reduce, reuse, recycle) (Prieto-Sandoval et al., 2018) which can lead to a transition from a linear to a circular economy and the development of new circular business models (Vence & Pereira, 2019).

[1] In our study the term "stakeholders" refers to actors (individuals, organisations) directly and officially involved in the project. For the others we used the word "actors".

The implementation of these loops *rests on innovations whose environmental purpose qualifies them as eco-innovations* (Prieto-Sandoval et al., 2018; de Jesus et Mendonça, 2018; Vence & Pereira, 2019). For these authors, eco-innovation is a central dimension of this transition. It is defined in the literature as a new or improved product, process, equipment, technique, or management system that eliminates or reduces its environmental impact (Horbach 2008, Vence & Pereira, 2019). Eco-innovation for the CE is therefore based on technological, but also organisational, institutional, and social innovations (de Jesus et al., 2018; Vence & Pereira, 2019 ; Galliano & Nadel, 2019). This non-technological dimension of eco-innovation is often central to CE processes in which the organization of loops requires the establishment of new links between economic actors (Hansen & Coenen, 2015).

Thus, although there are controversies as to the environmental value of this process (Bourdin et al., 2019), methanisation can be considered an eco-innovation in that it uses biomass residues to produce energy and is a process "by which organic material decomposes under the influence of microorganisms in the absence of oxygen" (Breeze, 2018). This process, also known as anaerobic digestion, is an example of the practical application of a CE solution since it involves transforming a material, which in most cases is a waste material or by-product, into energy (the biogas) and fertiliser (the digestate). In the collective projects, the meso-economic dimension is key since they are projects undertaken and implemented by groups of stakeholders that process agricultural and/or non-agricultural biomass produced by various activities in a territory (agriculture, food processing, distribution, green waste treatment, etc.). The integrative nature of these collective projects, that requires taking into account social and environmental dimensions, and the fact that they bring together different types of stakeholders, highlight the importance of exchange networks and interactions between stakeholders, i.e. the meso level of analysis of CE processes. We are therefore in line with the work aimed at shedding light on the place of eco-innovation and circular economy processes in the sectors covered by the bioeconomy (d'Amato et al., 2019).

1.2. Ressources for eco-innovations for the development of circularity: a meso level framework

As circular systems are built at different scales, the idea of eco-innovation towards circularity refers to different levels of analysis including i) a microeconomic level, with the analysis of individual actors and the technical, organisational and social changes they implement to develop eco-innovations (cleaner production of good and services, new business models etc.); ii) a meso level to examine the networks and interactions at work within green supply chains, sectoral systems and territories (eco industrial parks, eco-towns, etc.); iii) and a macro level to analyze the regulations and public policies and changes in the national systems of innovation. The meso level is particularly interesting to observe as it serves as an interface between macroeconomic dimensions and microeconomic dynamics. The systemic nature of the CE also highlights the importance of networks and exchanges between different stakeholders in sectors and territories. Thus, two dimensions can be explored to better understand processes of CE and how resources are used at the meso level: the impact of the external environment of the eco-innovative project in its various sectoral, territorial and institutional dimensions, and the role of networks and coordination between actors, which are at the heart of circularity.

1.2.1. Placed based and extra-local factors: the role of the external environment in eco-innovation projects

The literature on regional (Cooke, 2012; Camagni & Capello, 2013) or sectoral (Malerba, 2005) innovation systems highlights the importance of interactions between actors and their environment in their innovative performance. Beyond the sectoral and territorial dimensions, eco-innovation-based approaches also stress the importance of the institutional and regulatory dimensions (Rennings, 2000).

In an evolutionary perspective, the geography of sustainable transition highlights the importance of technological and industrial specialisation of a given area. In a smart developpement approach, projects develop on the basis of existing technological strenghts and the local industrial composition (Foray, 2019). On the other hand, as Hansen & Coenen (2015) note, few studies take into account the importance of local natural resource endowments in the analysis of environmental transition processes, either because that importance is "obvious" or because they are contingent on a type of project or location. Yet, they are important resources for eco-innovations that are based on the use of biomass, particularly in rural areas or territories of low economic density (Duque-Acevedo et al., 2020; de Jesus et al., 2018).

This low density has consequences on industrial diversity, and on the intensity of knowledge spillovers. In this type of configuration "related variety" type externalities, - which refer to the presence in the same region of different but technologically related activities (Frenken et al. (2007), can prove particularly beneficial. Our hypothesis is that in low-density areas, related variety can compensate for the lower concentration of economic activities (Camagni & Capello, 2013; Naldi et al., 2015; Galliano et al., 2019). The main positive effect of related variety is that it facilitates knowledge exchange on the territory (Neffke et al., 2011) insofar as the use of closely related technologies generates greater cognitive proximity between economic actors (Boschma & Frenken, 2011). Its effectiveness is also linked to the complementary nature of the knowledge exchanged, especially between old and new activities on the territory (Munro & Bathelt, 2014). Thus, the nature of the activities – and not just their concentration per se - on a territory does matter (Shearmur, 2015; Galliano et al., 2019).

Concerning institutional factors and regulation, studies on eco-innovation have placed special emphasis on the essential role of regulation and therefore of public policies (Rennings, 2000). The influence of this dimension varies according to the nature of the institutions and of the measures they implement. Governmental policies can play an important incentive or even coercive role in the adoption of eco-innovation (Horbach, 2008). But, as various studies have shown, place specific norms and values, as well as the measures or policies adopted by local or regional institutions also play decisive roles in locally-based eco-innovation projects (Hansen & Coenen, 2015). The literature on rural areas highlights the key role of public actors and their support in the different stages of innovative projects (Esparcia, 2014 ; Galliano et al., 2019).

These different dimensions are especially important in the case of collective methanation projects. The question of resources and of their proximity is central since the selection of a location for building a digester is conditioned by the proximity of biomass in sufficient quantity and quality (Zglobisz et al., 2010 ; Chodkowska-Miszczuk et al., 2019). The pedoclimatic and agricultural characteristics of territories therefore play a role in the development of these projects. The fact that projects to diversify agriculture toward related activities (e.g. agro-tourism) already exist in a territory also seems to play a role (Van Der Horst et al., 2018). These diversification strategies tend to 'activate' related variety, and in turn produce new links between activities in the territory. Thus, methanation projects and therefore the development and exploitation of a digester involve the establishment of relations with other local economic and institutional stakeholders (Chodkowska-Miszczuk et al., 2019).

Regarding the intersectoral dimension, the creation of loops in methanation projects calls for a more systemic vision of innovation based on the coordination between actors of various sectors (de Jesus et al., 2018 ; Konietzko et al., 2020). Such project is a type of venture where innovation dynamics are jointly generated by the agricultural sector which provide biomass and the energy sector which provides the anaerobic digestion technology and buys back the energy generated. It is therefore a potential means of activation of related variety in the agricultural

sector and of generating a new form of related variety between agriculture and renewable energy production.
As for national public regulations, they play a key role in the emergence and development of agricultural methanation. On the one hand, direct and indirect financial incentives (including guaranteed energy repurchase prices) have a major impact on the development of the supply and demand of biogas (Zglobisz et al., 2010 ; Yazan et al., 2018). On the other hand, these regulations are associated with more or less direct technical prescriptions, which condition both the technological choices of the actors of the sector and the size of the projects developed (Binkley et al., 2013; Auer et al., 2017).

1.2.2. Modes of access to resources: cooperation between actors and networks

At the meso-economic level, circularity raises the essential question of the interactions between actors and the networks on which they rest. Coordination between geographically close actors is often considered as an effective way to develop CE processes (Boons & Howard-Grenville, 2009). These interactions refer to the sharing of different resources, primarily materials (waste, etc.) but also technologies, knowledge and services. As de Jesus et al. (2018) have noted, promoting cooperations and interrelations between geographically close actors, companies and organizations is considered as an effective way of achieving more circular systems. In this context, eco-innovation is a key dimension in promoting new ways of sharing resources, constructing cooperations and new organizational models. The flow of resources in a CE process raises the question of the combined role of local and non-local, whose combination is often essential for innovation (Munro and Bathelt, 2014).

Regarding the types of actors, the literature highlights the importance of networks of cooperation between companies and public or private research for R&D activities (Maietta, 2015), as well as intra- and inter-sectoral relations with customers, suppliers and competitors (Klevorick et al., 1995). Concerning rural areas, studies note the specific importance of personal networks and of leading actors in the management of innovative projects (Esparcia, 2014) and the importance of access to institutional mechanisms, which then act in complementarity with personal networks (op. cit.). This literature stresses the key role played by the public actors and their support all along innovative projects, especially in rural areas (Esparcia, 2014; Galliano et al., 2019). The analysis of the interactions and networks between public and private actors at work throughout the innovation process often proves essential for understanding the development of eco-innovative projects in rural areas; with institutional actors facilitating the organization of the coordination between all the stakeholders.

In the context of methanation, the pooling of the resources necessary for the digester to function is a phase that generates new interactions between diversified actors, which in turn, generates organisational innovations towards new modes of coordination. As Bourdin et al. (2019) have shown, institutional actors are intermediaries that play a particularly important role in renewable energy projects due to the diversity of stakeholders. As shown by various studies, collective methanation projects involve the creation of networks of collaborators at different production stages (Chodkowska-Miszczuk et al., 2019; Bourdin et al., 2019) and of new coordinations between agriculture, energy, public actors but also citizens.

2. Methodology: mixed data-analysis of methanisation projects

The analysis is based on case studies of anaerobic digestion projects. For each project, we analyze the factors that explain their emergence and dynamics, the resources mobilized throughout the project and the changes that have taken place in the networks during the process. For this purpose, we use and expand a “mixed” method, the « Quantified Narrative Method » which is particularly well suited for studying innovative processes and their dynamics (2.1). We then present the criteria of selection and main characteristics of the case studies (2.2).

2.1. The quantified narrative method

To collect and analyze the information from case studies, we use the Quantified Narrative Method, which is originated from economic sociology and was developed by Grossetti (2011). It consists in first collecting the narratives of key stakeholders over the entire project life cycle, taking care to identify the resources they have used and how they obtained them. Each resource acquisition will be considered as an "access sequence" whose characteristics are coded. A quantitative analysis can then be carried out based on the coding of resources. The main advantage of this coding and of the quantification it allows for lies in facilitating the objectification of the dynamics of resource acquisition, in line with the mixed data-analysis method (Small, 2011). This method usually allows, after a few cross interviews, to have a stabilized narrative characterizing the main resources mobilized during the project's trajectory (Grossetti, 2011). To allow for this, the investigator must be systematic in his requests for precision, particularly with regard to the modes of access to resources, or the periods in which the reported events take place.

We first present what is involved in the characterization of resources before examining what pertains to the dynamics of the project. In this presentation, we will specify what makes our contribution original from a methodologial point of view.

The characterization of the resources is intended to help answer the following questions: what is the nature of the resource, who supplies it, how do the stakeholders access the resource? And where is it located? The resources are characterized by the following features:

- We distinguish 8 types of resources using an approach typically used in studies on innovation and aimed at identifying the different needs of an organisation: raw materials and technology, R&D, human resources, training, advice, funding, organisation and marketing, and outlets.
- We perform a dual categorization (activity and nature) of the resource provider. For activity, we distinguish 3 types of suppliers: AGRI refers to those involved in an activity related to agriculture (including professional organizations and Chambers of Agriculture); ENER refers to those involved in an activity related to energy; and OTHER refers to those involved in another field of activity. These are mainly administrations (local authorities, development agencies, decentralised State services, etc.), financial institutions and actors in other sectors (construction, legal, etc.). The purpose of this categorization is to determine the levels of specialization and/or related variety (Neffke et al., 2011) of the resources that flow between the organizations. By also taking into account the type of seeker, we will be able to verify whether the exchanges tend to occur between specialized actors (agriculture or energy) or whether bridges are built between agriculture and energy, which would indicate a development of related variety between these two sectors. Furthermore, we seek to determine whether the provider is a for-profit commercial actor or an institutional actor. Institutions refer here to public organizations (administrations, educational and research institutions, development agencies, etc.) but also private bodies such as consular chambers, training organisations, professional associations or federations. For-profit commercial actors refers exclusively to enterprises in the form of companies or individual entrepreneurs (customers, suppliers, competitors, subsidiaries, etc.).
- A resource can be accessed either via personal networks or information dissemination mechanisms. Thus, access to the resource can be obtained through someone known to

one of the project members. This person may be part of the organisation providing the resource, but may also have served as an intermediary between the project member and the resource provider. When no such relation exists with the provider, the resource can then be obtained via an information dissemination mechanism: technical tools (internet, digital tool), other media (press, catalogue, book, etc.) or mechanisms for connecting actors (trade fair, seminar, call for tenders, etc.).

- The location of the resources is indicated using four levels of geographical distance. The "local" level refers to a location within 50km of the project location. The other three levels correspond to the regional (Nuts2), French and foreign levels.

Beyond the data concerning resources, additional information about the governance of the projects has been collected, in particular on the meetings for project steering (participants, frequency, issues discussed and modes of decision-making). Data on the general characteristics of the project (size, type of products, actors involved, legal status of the organization that supports the project …) are also collected to ensure the most complete information possible on the project.

The key events are identified using an approach in terms of resource dynamics. In innovation studies that use this type of approach, project dynamics are typically addressed by dividing the project into phases (Galliano et al., 2019; Negro et al., 2007). Each sequence of procurement of resource is then positioned in one of the phases of the project studied. In the case of methanisation projects, we are faced with a specific problem, which is related to the length of genesis and feasibility phases of the projects. Thus, of the 4 projects studied that started between 2005 and 2012, only one had just started the methanation plant. The identification of the phases is therefore based here on that of key events that have marked all the methanisation projects and which correspond to structuring phases during which important decisions were made (see Figure 1).

Figure 1: The different phases of the anaerobic digestion projects studied

The methodology is therefore based on narratives from in-depth interviews with the main actors of the project, on a transcription by the researcher of the interviews, which is then sent back to the interviewees for validation, and then on coding performed by the researchers on the basis of the materials collected and validated. Finally, the results are summarized in tables to facilitate the comparison between projects but above all to allow for a transversal and aggregated analysis of the projects.

2.2 Characteristics of the four rural methanation projects

We have used two main criteria to select our case studies. The first criterion was the collective dimension of the projects: They had to involve several actors and be founded and managed by collective structures, as opposed to individual projects involving a single company. In particular, they had to involve several farms. Secondly, the projects had to have sufficient temporal length, i.e. they had to have gone through all the phases of development up to the actual development of a methanation facility.

The projects were identified thanks to different sources of information: local and regional press, exploratory interviews with local and regional authorities and agencies, etc. The collective agricultural methanisation projects are still rare in Occcitania region. We were therefore able to investigate all the collective projects mature enough to be analysed in terms of trajectory.

Three projects are located in the *département* of Aveyron and the fourth is in the *département* of Ariège. These rural *départements,* according to Edora typology, are situated far from big cities (Dijkstra & Poelman, 2011). This remote rural dimension is an important aspect in the dynamics of these projects and must be taken into account. These projects involve a significant number of farmers (between 28 and 70) and two projects were initiated by farmers. In the other two projects, a collective of actors was formed for the purpose of initiating the project. Three projects involve breeders while the 4th involves producers of maize and rapeseed seeds (cf Table 1) .

Table 1: Main characteristics of the projects

We conducted the first interviews with a project leader who was more particularly involved in the genesis phase. Other interviewees were identified during the first interview or the next, following the relational chains method. Other works based on this method have shown that a limited number of interviews with the project leader(s) and possibly key partners made it possible to arrive at a saturation of information enabling the identification, qualification and quantification of the resources mobilised and their methods of acquisition (Grosseti, 2011). The number of interviews varies from two for Arseme to five for Centrès. Sixteen interviews – of an average length of one hour and twenty minutes - were conducted between 2015 and 2018. After each interview, a synthesis was sent to each person for validation. In some cases, some additional questions were asked to obtain complementary information about the resources.

Using the Quantified Narrative methodology, we extract from the narratives the relevant information concerning the sequences of access to resources, in accordance with the defined theoretical and methodological framework. The coding resulted from a cross analysis conducted by the three authors. A chart for each project summarizes the information on each resource cited by the interviewees and coded by the researchers. Each sequence of access to a new resource is part of one the four phases of the project.

Table 2 indicates the number of external resources used by the four projects.

Table 2: Distribution of resources for the four projects

The total number of resources for the four projects is 167. As the first two projects were initiated earlier than the other two, they had used slightly more resources. However, this does not mean that they were completed more quickly. The Methanaubrac project was in the most advanced state of development, which explains the greater number of resources for the construction phase. The number of resources used for the feasibility phase also varies strongly from one project to the other, because some projects encountered structuring difficulties in this phase.

3. Results

This section presents the results regarding the meso-economic factors for the development of anaerobic digestion projects, calculated on the basis of the aggregated data of the 4 projects studied. First, we present the resources on which these projects draw. We then analyse for the different phases of the projects how these resources were acquired in order to show the role and nature of relational networks and their dynamics.

3.1. The key role of the location throughout the projects

The results firstly confirm that local resources (Hansen and Coenen, 2015) are decisive for methanation projects (Yazan et al., 2018; Chodkowska-Miszczuk et al., 2019).

Table 3 : Location of resources for each project phase

Table 3 presents the geographical distribution of the resources acquired by the organizations conducting the projects during the different phases. The results highlight the preponderant share of local resources (i.e.found within 50km). Indeed more than half of the material and immaterial resources used are accessed locally, although there are variations from one phase to the other. The resources found at regional level also account for a large part of the total resources, particularly during the feasibility and development stages. This can be explained by the fact that during these stages the need for resources provided by regional institutions – funding in particular - is significant, which confirms the role of this factor in the development of methanation projects (Bourdin et al., 2019). The share of resources found outside the region – that is in France or abroad - is much larger during the genesis and development phases than during the other phases of the projects. This can be explained by the fact that during the genesis phase, project leaders need to collect preliminary information about a technology that is not widely used locally and a type of collective project that has seldom been undertaken in the region. The actual phase of development of the digester requires specific technologies and know-how that a limited number of companies – which often operate internationally[1] – can provide. The feasibility and implementation phases correspond to a project structuring stage for which the necessary resources can more easily be found locally or regionally. Figure 2 corroborates this finding.

Figure 2: Location of resources according to their nature

Figure 2 shows that the spatial distribution of the resources acquired varies according to their nature. It shows that a large majority of the resources are found locally, that confirms the importance of this territorial scale (as shown by Yazan et al., 2018), particularly for the input (biomass, livestock manure) fed into the digesters as shown by (Chodkowska-Miszczuk et al., 2019). Training resources (which are mostly related to project engineering capacities) are also mostly found locally and are often provided by agricultural institutions (Chamber of Agriculture in particular). The few R&D resources needed for the projects - which correspond to prototype equipment to collect biomass – are also mostly found locally. This shows that there are local innovation capacities in these sparsely populated areas, which reverses the assumption commonly make regarding this type of area (Shearmur, 2015). The "Org&Marketing" resources correspond to the services and expertise needed by the project leaders. They most often concern support for project set-up, technical expertise or mandatory studies and procedures. In this category, almost everything related to the agricultural component of the project is provided by local agricultural institutions. The rest is mostly provided by regional actors (including consulting firms) whose expertise is based on their experience of other projects developed in Occitania.

The sources of funding are many and geographically dispersed, which is explained by the high cost of these projects: contributions from the project leaders, grants from local and regional

[1] https://www.europeanbiogas.eu/wp-content/uploads/2019/05/Companies-Catalogue-EBA-2018.pdf

authorities, loans from public or private banks. A small share of local or national crowdfunding can be introduced, particularly to increase the acceptability of these often contested projects, as Chodkowska-Miszczuk et al (2019) and Bourdin et al. (2019) point out. The "advice" resource is found at all territorial levels. Those found in France and abroad are either information obtained informally throughout the genesis phase during visits to other project leaders or advice provided by methanation specialists. Approximately 20% of the means of production necessary for the construction and operation of the digester originate in France or abroad. Regarding "outlet" type resources, the important share of national sources is explained by the fact that the energy produced is fed into the general grid and sold to national operators. These non-local energy actors therefore play a key role in the very existence of the projects (cf. Lajdova et al., 2016 on the role of energy players in the development of anaerobic digestion in Germany).

Thus, we find that the local territory plays a major role in the structuring of these projects, in that it provides the majority of the resources and almost all those related to the agricultural component of the project. However, the actual availability of local agricultural resources is very dependent on how the local agricultural sector is structured (Van Der Horst et al., 2018) and on its dynamics of innovation (Malerba, 2005). Furthermore, these projects also rely on the complementarity between local, regional, national and international levels, insofar as a significant number of the non-agricultural and mostly intangible resources originate in the region or even beyond.

3.2. Towards an inter-industrial relatedness

In this sub-section, we analyze the sectoral linkages that emerge through these projects and the dynamics of development of related variety. The connections between sectors develop both through the internal structuring of the project and through the external resources acquired. This double movement leads us to focus on who asks for the resource and who provides it.

The actors who ask for resources are the various individuals and organisations that play an important role in the different phases of the project. The structuring of these organizations is in itself an indicator of the related variety processes that take place throughout the projects. First of all, the running of these projects greatly relies on the creation of links between agriculture and other types of activities, as shown by Bourdin et al. (2019) and Chodkowska-Miszczuk et al. (2019). Thus, we were able to distinguish 3 types of seekers of resources (agri, agri/ener and multi). AGRI refers to collectives composed exclusively of farmers/agricultural sector actors, AGRI/ENER refers to a combination of actors from the agricultural and energy sectors, and

MULTI refers to a mix of actors from several sectors: actors in the farming and sometimes energy sectors, but also local authorities and even civil society. AGRI and MULTI are configurations of actors that are active from the onset of the projects. On the other hand, AGRI/ENER refers to organizations that get involved at the beginning of the implementation phase following the feasibility study. Those projects are structured into two levels: A first organization formed by an AGRI or MULTI collective and which tends to focus on the agricultural component of the project; and a second organization formed and run by an AGRI/ENER collective – whose focus is more on the energy component and overall steering of the project - and in which the AGRI or MULTI collective remains a decision-maker. This configuration is observed in 3 of the 4 projects studied. It is indicative of the connections that farmers build with actors from other sectors in order to carry out these projects, but also of the difficulties to implement a truly integrated project management – as the persistent partition between the agricultural and energy components shows, the negative effect of which on the development of methanation projects is underlined by Negro et al. (2007).

Figure 3: Phases of resource mobilization according to the status of the resource seeker

Figure 3 shows that AGRI collectives are active throughout the projects as seekers of resources. The MULTI collectives are mainly involved in the genesis of the projects and during the feasibility phase. And, as previously indicated, the AGRI/ENER collectives become involved from the project implementation phase onwards. This late involvement of energy actors is mainly due to the fact that the originators of these undertaking try to keep maximum control over their projects so as to be able to meet their goals in terms of durability. To this end, they seek, from the onset of the project to federate local actors who share the same goals as themselves. This dynamic is relevant in that, as Cavicchi et al. (2017) have shown, a lack of local synergies around methanation projects can have a negative influence on their sustainability.

Regarding the suppliers, we rely on the typology of activities in 3 fields: agriculture, energy or other.

Figure 4: Phase of resource mobilization according to sector of activity

Figure 4 shows first of all that agricultural resources are used throughout the entire project, although less so during the construction phase, in which resources from ENER and OTHER are used more. ENER resources also come significantly into play during the feasibility phase, when the project’s technical orientations (size, technology to be favoured, conditions of profitability...) are outlined. This is a good illustration of Lajdova et al. (2016)'s conclusions on the role of the energy sector in agricultural projects. Resources from other sectors (OTHER) are little used during the genesis phase. However, they come strongly into play in the feasibility phase, during which local and regional authorities and agencies become involved. This shows that public intermediary actors play a more important role in certain stages of collective projects (cf. Bourdin et al., 2019). In short, the figure illustrates that the need for agricultural resources alternates with the need for resources from the energy and other sectors, according to the project's phase. The need for AGRI resources is particularly important during the genesis and development phases, while the need for ENER and OTHER resources increases during the feasibility and development phases.

We can further develop our analysis of intersectoral linkages by cross-referencing the data on the activities of resource seekers with the data on those of resource providers.

Table 4: Provider of the resource according to the activities of the resource seeker

Table 4 indicates that farmer collectives tend to use larger proportions of agricultural resources than other resource seekers. However, a non negigible share of the resources they use come from the energy sector, which points to a development of relations between these two sectors. For the AGRI/ENER collectives, which get involved at the beginning of the development phase, the aim appears to be to mobilize all types of resources necessary for the energy production phase of the methanation project. Within the same project, there appears to be a division of tasks between the initial AGRI or MULTI collective, which manages the agricultural component of the project, and the AGRI/ENER organization, which focuses on the energy component by taking on the task of procuring the resources necessary to develop and build the digester. This reflects a construction of intersectoral relations even though, as highlighted above, the latter only operate during certain phases of the projects. Finally, the MULTI collectives mobilize the three categories of resources in approximately the same proportions. This concerns projects whose initiators have from the outset sought to include a variety of actors present in their territory in order to ensure the sustainability of the project (Cavicchi et al., 2017) and which seem to have the capacity to mobilize resources from different sectors.
Thus, by crossing the data relative to the type of ressource seekers with the data on suppliers of resources, we observe several dynamics that testify to the development of a new form of related variety associating agricultural actors, energy actors, public actors and even citizens.

This new kind of "green collective innovations" (de Jesus et al., 2018), exploit the related variety (Camagni and Capello, 2013; Naldi et al., 2015) which is activated to acquire the external material and immaterial resources needed for the different stages of the project. These methanisation projects testify to the development of complementarities between old and new activities, which play a central role in the innovation dynamics of territories (Munro & Bathelt, 2014). By gathering very different actors, the building of circularities, leads to a broaden related-variety, even if that related variety is only partially built since each sector (agriculture and energy) tends to keep within its own areas of competence and intervention.

3.3. Networks and types of actors

In this sub-section, we analyse the role of networks in the development of the projects studied, as well as the nature of these networks.

Table 5: Modes of access to resources according to their location

Table 5 shows that personal linkages play an important role in the acquisition of the resources necessary to develop projects, which points to a strong degree of embeddeness, and is in line the findings of other studies on rural eco-innovation (Esparcia, 2014; Galliano et al., 2019). Thus, more than 70% of the resources are obtained through personal linkages. In France, the part played by personal networks decreases with distance, which is also consistent with the literature (Grossetti, 2011; Galliano et al., 2019). A more surprising result - which must be considered with caution because it only concerns four resources - is that resources of foreign origin are obtained via personal commercial relations. This tends to point to the important role played by personal relations in opening these types of projects to their international environment.

Figure 5: Access to the resources according to their nature

Figure 5 shows that access to resources depends on the nature of the resource. The recourse to information dissemination mechanisms is only significant (> 25%) when stakeholders seek "outlet" resources, i.e funding and means of production. This reflects the fact that the project leaders must follow conventional procedures such as calls for tender or grant application to obtain ‘outlet’ resources, funding and means of production. This is also the case for projects that aim to sell the energy they produce via contracts with national operators, with which the project leaders have no connection initially.

Figure 5 also shows that the weight of institutional and market actors varies according to the type of resource. Thus, we note that institutional actors play a greater role in providing resources such as human (advice, training), organizational and financial support of the project than in providing other types of resources. This is a reflection of the public policies adopted at different levels to promote biogas, and which take the form of support, funding, or even of direct investment in the projects. This confirms the results already highlighted on the role of local public actors (Bourdin et al., 2019) and public policies at different levels (Binkley et al., 2013; Auer et al., 2017). As this category also includes Chambers of Agriculture and other professional agricultural organizations, its weight also reflects the importance of the traditional actors of the agricultural innovation system (Malerba, 2005).

Table 6: Mode of access to resources according to project phase

Regarding the mode of access to resources according to project phase, Table 6 highlights the importance, throughout the project, of personal linkages. Indeed, they account for the vast majority (88.4%) of the resources obtained in the project implementation phase, with a slight decrease in the development phase (57.1%). There is therefore no clear break in the role of personal networks from one phase of the projects to another, and the weight of institutional actors remains significant throughout the process. This finding is also consistent with those of other studies on networks for eco-innovation in rural areas (Esparcia, 2014; Galliano et al., 2019) and for methanation (Bourdin et al., 2019). The weight of personal relations in the implementation phase is due, among other things, to the strong need for consulting and organizational & marketing resources, which exist and can be found locally. In the development phase, on the other hand, there is an increased use of market and institutional mechanisms to obtain the means of production and the necessary funding for construction.

This work confirms the importance of personal networks in such processes (Bathelt et al., 2004; de Jesus et al., 2018; Bourdin et al., 2019) and corroborates the results regarding the embeddedness of multi-actor innovation activities in rural settings, obtained by previous studies on agri-food (Galliano et al., 2019) or other types of projects (Esparcia, 2014). More specifically, this work highlights the importance, throughout the project development process, of the relations between project leaders and institutional actors, and of intra-sectoral links. More specifically, it shows the significant role played by local and regional relations.

4. Conclusion

Through this study we have sought to shed light on the scales and dynamics of resource use and circulation that promote innovation towards CE practices. For this purpose, we have focused on collective agricultural methanisation projects – and particularly on the role of networks and collaboration - which have been little studied in the social science literature. We have used an original theoretical framework based on the literature in economics, the geography of innovation, and eco-innovation, starting with the hypothesis that eco-innovations, whether technological or organizational, are a crucial factor in the implementation of a CE approach (de Jesus et al., 2018). Finally, we have adapted and used a mixed method, the "quantified narrative method" (Grossetti, 2011), which is particularly interesting for analysing innovation trajectories. Four projects involving farmers' collectives were investigated, with a special focus on the external resources mobilised by the stakeholders throughout the projects. Our in-depth analysis of the 167 resources mobilized by the projects has enabled us to highlight a number of eco-innovation mechanisms that promote the development of a circular economy in rural territories.

In terms of determinants, our results confirm the role of key eco-innovation factors identified by the literature: local material and immaterial resources, sectoral and institutional environment, i.e. a combination of place-based and extra-local factors. Moreover, we have found that regulations, at different levels (European, national, regional and local), do indeed play a decisive role. Finally, this work also confirms the importance of personal networks in such processes and corroborates the results regarding the embeddedness of multi-actor innovation activities in rural settings, obtained by previous studies on agri-food (Galliano et al., 2019) or other types of projects (Esparcia, 2014).

Regarding the effects of these projects, through their governance and the mobilization of the necessary resources, these processes generate new relations between agriculture, other economic activities, public actors, actors in the energy sector and, sometimes, citizens. This allows us to consider that circularity can be analysed as an extension of related variety, which, in the present case, develops around a technological innovation that generates a number of organizational innovations. However, this construction of circularity is not self-evident and often remains incomplete since each sector (agriculture and energy) tends to keep within its own areas of competence and intervention. The long time needed to implement these projects testifies to their difficulties.

The results show the meso-economic dynamics at play in these projects, with the use of local resources and a development of local synergies, thus confirming the observations made by de Jesus et al. (2018) according to whom the creation of circularity is based on new "green collective innovations" on a territorial scale. These results, observed in rural areas, confirm that these low-density areas can be fertile ground for innovation dynamics, contrary to what is generally suggested in the literature on innovation economics.

In this article, we have highlighted the key role played by public policies at different levels in the development of these projects. However, this study also shows that these policies need to evolve if they are to foster a rapid development of such projects. Beyond financial support and advice, taking into account the specificities of each project (not only technical but also those related to the type of collective involved and the territorial context) and building a concerted and shared vision by facilitating exchanges between project leaders and between actors in the agricultural and energy sectors, seem to be two important avenues for the development of public action.

Beyond the increase in the number of cases studied by the extension to other territories, we identify two relevant tracks to pursue this research: The in-depth analysis of the role of institutional actors in the structuring of methanisation at the regional scale and the study of the effects on territories of the development of this activity, particularly the new material and immaterial resources generated for local areas and the surrounding territories (especially in the region).

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Captions List

Figure 1: The different phases of the anaerobic digestion projects studied

Table 1: Main characteristics of the projects

Table 2: Distribution of resources for the four projects

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Table 6: Mode of access to resources according to project phase

Table 1: Main characteristics of the projects

Project	Organization that initiated the project	Technology	Year of initiation of the project	Main contributions
Centrès	Multi-stakeholder association (farmers, elected officials, citizens)	Biomass cogeneration	2008	Livestock manure (26 breeders)
Montbazens	Multi-stakeholder association (farmers, elected officials, enterprises, civil society)	Direct injection	2005	Livestock manure (70 breeders)
Methanaub	Farmers association	Biomass cogeneration	2010	Livestock manure (28 breeders)
Arseme	Farmers association	Direct injection	2012	Corn stalks (56 farmers

Table 2: Distribution of resources for the four projects

Project	Genesis	Feasability	Implementation	Development	Total (Number)
Centrès	14.3	46.9	22.4	16.3	100.0 (49)
Montbazens	22.7	34.1	27.3	15.9	100.0 (44)
Methanaubrac	13.2	18.4	21.1	47.4	100.0 (38)
Arseme	13.9	27.8	33.3	25.0	100.0 (36)
Total	**16.2**	**32.9**	**25.7**	**25.1**	**100.0 (167)**

Tableau 3 : Location of resources for each project phase

Phase	Local	Regional	France	Abroad	Total (number)
Genesis	55,6	22,2	14,8	7,4	100,0 (27)
Feasability	54,5	41,8	1,8	1,8	100,0 (55)
Implementation	62,8	30,2	7,0	0,0	100,0 (43)
Development	38,1	47,6	11,9	2,4	100,0 (42)
Total	**52,7**	**37,1**	**7,8**	**2,4**	**100,0 (167)**

Table 4: Provider of the resource according to the activities of the resource seeker

Provider / Seeker	AGRI	ENER	OTHER	Total (number)
AGRI	41,5	26,2	32,3	100,0 (65)
AGRI/ENER	10,0	50,0	40,0	100,0 (40)
MULTI	32,3	35,5	32,3	100,0 (62)
Total	**30,5**	**35,3**	**34,1**	**100,0 (167)**

Significance of the chi2 test: 0.0129

Table 5: Modes of access to resources according to their location

Location	Personal link to		Mediation device		Total (number)
	Market actor	Institutional actor	Market actor	Institutional actor	
Local	42,0	37,5	9,1	11,4	100,0 (88)
Region	30,6	33,9	19,4	16,1	100,0 (62)
France	23,1	15,4	61,5	0,0	100,0 (13)
Abroad	100,0	0,0	0,0	0,0	100,0 (4)
Total	**37,7**	**33,5**	**16,8**	**12,0**	**100,0 (167)**

Table 6: Mode of access to resources according to project phase

Phase	Personal link to		Mediation device		Total (number)
	Market actor	Institutional actor	Market actor	Institutional actor	
Genesis	29,6	33,3	25,9	11,1	100,0 (27)
Feasability	38,2	34,5	10,9	16,4	100,0 (55)
Implementation	46,5	41,9	7,0	4,7	100,0 (43)
Development	33,3	23,8	28,6	14,3	100,0 (42)
Total	**37,7**	**33,5**	**16,8**	**12,0**	**100,0 (167)**

Figures

Figure 1: The different phases of the anaerobic digestion projects studied

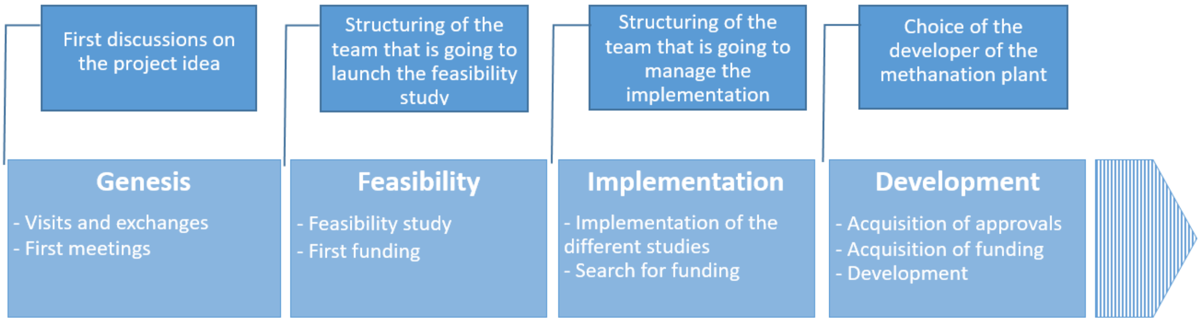

Figure 2: Location of resources according to their nature

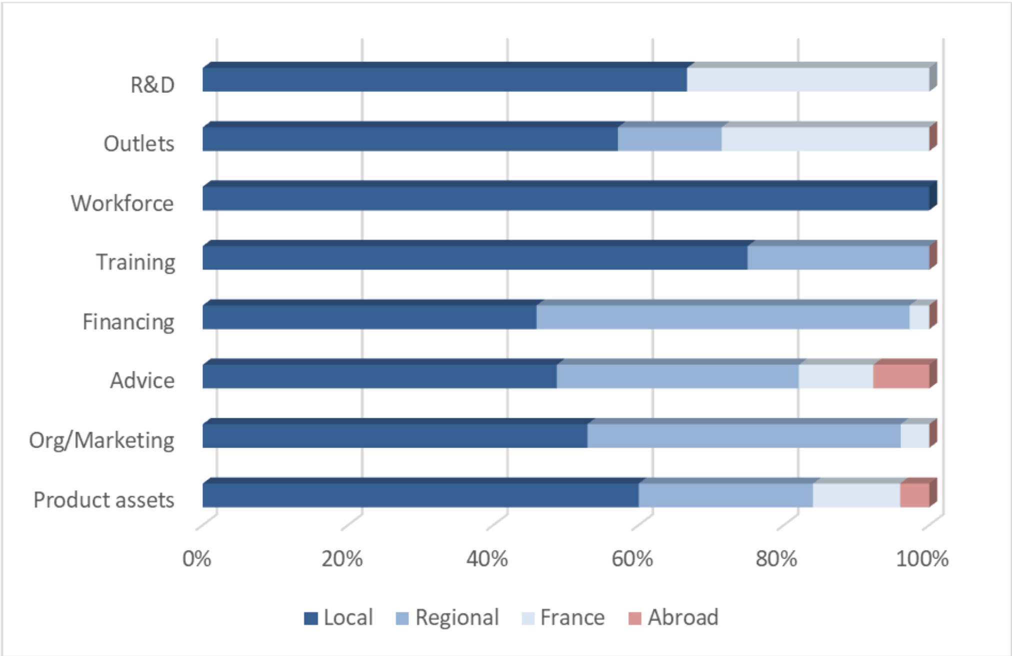

Figure 3: Phases of resource mobilization according to the status of the resource seeker

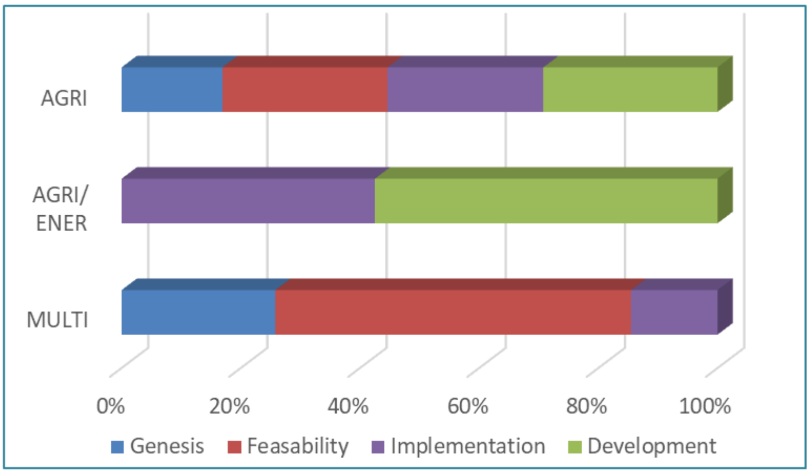

Figure 4: Phase of resource mobilization according to sector of activity

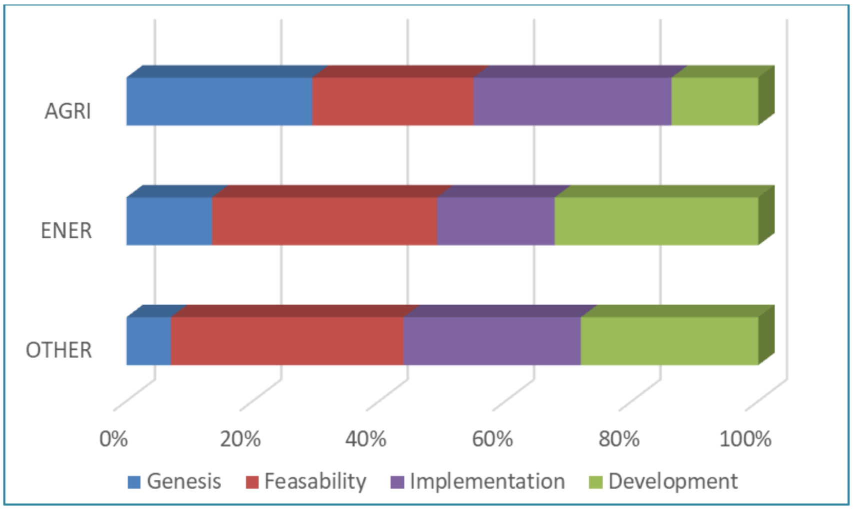

Figure 5: Access to the resources according to their nature