



# How do local actors coordinate to implement a successful biogas project?

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## ABSTRACT

Anaerobic digestion has recently gained interest in contributing to territorial strategy regarding the deployment of the circular economy and energy transition. Most projects bring together multiple actors from a wide variety of backgrounds. The article analyzes the evolution of synergies and cooperative behaviors between local stakeholders over the period 2010–2020 in an anaerobic digestion cluster in France. The study draws on social network analysis and proximity theory, which have recently been used for analyzing regional innovation systems, local clusters, territorial governance, and rural development. We reveal that local stakeholders develop dense relational networks that vary and evolve throughout the project. Different groups exist and behave in a semi-autonomous manner. All the actors are located in close geographical proximity. Still, their links in terms of organized proximities are related to various types of relations, resulting from cognitive resemblances or common origins. This explains the persistence and resilience of local relationships and how they maintain a collaborative dynamic over time.

## 1. Introduction

Resource scarcity, biodiversity erosion, the degradation of natural ecosystems, and global warming are environmental challenges currently facing human societies. They require us to limit the consumption of resources that nature cannot regenerate and drastically limit the polluting emissions of economic activities. The supplies of fossil or non-renewable energies (oil, natural gas, coal), which are constantly decreasing as the global energy demand increases due to population and economic growth, are particularly concerning (Krausmann et al., 2009). In addition to their imminent depletion (Klass, 2004), these energies are known for their potential to emit greenhouse gases (GHG), which are at the root of climate change.

In this critical context of environmental degradation, the European Union wishes to increase the share of energy from renewable sources in the energy mix. To this end, it has put in place several public action schemes that commit the Member States to increasing the share of renewable energy consumption to 32% (European commission, 2014). Anaerobic digestion (AD) is one of the solutions adopted by most European countries (Jacobsen et al., 2014; van Foreest, 2012; Engdahl, 2010); it is part of the European Commission's bioeconomy agenda and the "Green Pact for Europe," which aims to ensure the transition to a

resource-efficient and climate-neutral society by 2050 (European commission, 2019).

AD is the production of biogas and digestate from a biotechnological process of transforming plant biomass, such as crop residues, livestock manure, household waste, or bio-waste, from food processing companies (Angelidaki and Ellegaard, 2003; Holm-Nielsen et al., 2009). Biogas can be reused as fuel for a boiler to produce heat for facilities and buildings for collective use, transformed into electricity and heat at the same time by a cogeneration engine, used as fuel for vehicles, or after purification, injected into the urban natural gas network. After a maturation phase, the digestate is used as an agricultural fertilizer to replace chemical nitrogen fertilizers.

Since 2010, following the National Action Plan for Renewable Energies, this energy has been particularly encouraged in France. It has gained even more interest recently through its contribution to the territorial strategy for deploying the circular economy, included in the 2015 Law on Energy Transition for Green Growth and reaffirmed in 2019 by the Energy Climate Law. AD must allow territories to create circularities to increase the national production of organic nitrogen fertilizer and energy from local biomass. The objective is to increase the share of renewable energy to 10% of gas consumption and 40% of electricity consumption by 2030, helping to reduce pollution and GHG

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emissions by 75% by 2050 compared to 1990 levels.

The objective of the Ministry of ecological transition plan was to create 1000 CE plants by 2020, despite only about 700 existing in 2019, including 340 individual on-farm AD projects using the resources of the holder's farm and 49 territorial AD projects. The latter are more ambitious projects, with an industrial dimension for the management of agricultural waste, agri-food bio-waste, green waste, and household waste, allowing the production and consumption of renewable energy. Their collective dimension leads them to establish or use links and to set up exchanges between the numerous local stakeholders at the crossroads of territorial, institutional, and environmental dynamics.

Implementing AD at the territorial level can be considered as a pragmatic response to the slogan "think global, act local", which was the basis of some reflections on sustainable development (Darier and Schüle, 1999). Indeed, it appears to be an important component of circular economy strategies, probably more modest than the initial sustainable development goals, but anchored in concrete and territorialized actions. However, we must not be naive about this. If circular economy is defined above all by the increase in the duration of life of objects and the reintegration of the outputs in the production, in the form of inputs or energy, it is not always virtuous in its present form: sending goods for recycling to the other side of the world is not a guarantee of reducing global warming. Thus, anchoring in the territories is essential, with the importance of local retroaction loops (Veyssi re et al., 2021; Bourdin et al., 2021). In other words, following recent contributions, we postulate that territorial anchoring/local embeddedness is a condition to develop projects from the bioeconomy and the circular economy that are truly virtuous from an environmental point of view.

In this sense, this reflection is also in line with the literature on clusters and industrial districts where it has been highlighted how territorial contexts, actor networks and the social relations they maintain can either stimulate or hinder the development of projects (Lazzeretti et al., 2019). Yet, previous studies on circular economy models (like in industrial ecology, industrial symbiosis) have highlighted the need for organizations involved in a project to be clustered, in order to facilitate the collaboration and the exchanges of material and immaterial flows (Aarikka-Stenroos et al., 2021). From this point of view, studies analyzing the different forms of proximity in clusters (Broekel and Boschma, 2012) are useful for understanding how actors coordinate to develop a successful project. For example, Polge and Torre (2018) have shown how geographical proximity between stakeholders can facilitate collaborations and exchanges and how the establishment of an effective territorial governance can favor the success of a project.

Despite the growing number of applications for implementation, most AD projects fail due to difficulties in making investments profitable (Zemo and Termansen, 2018) and often as a result of the resistance of local populations, which can hinder the implementation of infrastructures (Bourdin and Nadou, 2020). The literature on social acceptability issues in territories (Schumacher and Schultmann, 2017; Zemo et al., 2019; Soland et al., 2013) argues that these fall under proximity conflicts of the same order as those concerning wind turbine development (Tegou et al., 2010) or other household waste treatment facilities (Mengozzi, 2010). They arise because of concerns about the production of negative externalities related to environmental damage and nuisances, such as noise or odor pollution, and the decline in real estate values (Schumacher and Schultmann, 2017; Zemo et al., 2019). But the literature has recently highlighted that the problems of biogas deployment can also be explained by difficulties in terms of territorial governance (Bourdin et al., 2020). AD projects often experience difficulties related to the diversity of stakeholder actors, whose modes of operation diverge (Torre and Wallet, 2014), making collaboration and project success difficult. Thus, despite its environmental virtues and potential to create value and anchored jobs (Guenther-L ubbers et al., 2016), the capacities of AD with regard to bringing together multiple actors from diverse universes remain highly questioned. This questioning is in line with what is currently being discussed in the literature on

the bioeconomy and circular economy in the social sciences, namely the capacity of actors to coordinate and implement effective territorial governance (Sanz-Hern andez et al., 2019; Lenglet et al., 2021; Marty et al., 2021). In this context, our paper contributes to this theoretical field aiming to better understand the extent to which territorial governance plays a determining role in the deployment of the bioeconomy and circular economy.

Few works address this issue of organizing actor games and coordinating local stakeholders in AD processes. We seek to shed new light on the coordination processes between actors in renewable energy projects and provide a complementary perspective to the emerging literature on the territorial governance of AD projects and more generally on the theoretical framework on the role of the coordination between stakeholders to implement successful bioeconomy and circular economy projects. While previous studies have focused on the social acceptability of these projects, our article focuses on the study of proximity relationships and exchanges between actors to ensure that the project can be implemented and sustained over time. Specifically, we question the extent to which locally anchored multi-stakeholder collaborations facilitated by geographic and organizational proximity can overcome the challenges and barriers that green, sustainable or circular economies face at the local level. As mentioned before, this is all the more important since recent studies have shown that, beyond the aspects related to social acceptability, one of the recurring problems encountered by project leaders—and which can be detrimental to the project—is the absence or lack of coordination between actors (Bourdin et al., 2020). We thus analyze for the first time the structuring of the territorial governance of an AD project based on the analysis of relations between actors. It allows us to understand the evolution of networks by highlighting the conditions of the creation and renewal or disappearance of synergistic relationships between actors and the role of their local embeddedness.

Our article aims to analyze the dynamics of social and economic interaction links and proximity relations by integrating the potential for conflict and the role of public interventions. From a theoretical point of view, our article combines in an original way two approaches to understanding the dynamics of coordination between actors that favor the deployment of successful projects. More precisely, we use the approaches of social network analysis and the School of Proximity to analyze territorial governance, applied to the AD system of the Syndicat Mixte du Point Fort (SMPF). This case study is symptomatic of the problems of linking actors at the local level. Stakeholders with varied functions and different territorial scales coordinate with regard to issues of waste mobilization, co-product disposal, risk management, and social acceptability.

It is interesting to evaluate the effectiveness of this mechanism in terms of territorial governance and to highlight the measures by which actors of different natures (producers, associations, individuals, representatives of public authorities or local communities, etc.) contribute to the elaboration, sometimes concerted, sometimes conflicting, of common territorial development projects (Torre and Traversac, 2011). Recently mobilized in the example of AD in Cavigny (Niang et al., 2021), the social network tool is here coupled with an analysis of proximities (geographical and organized) to provide a better understanding of the governance associated with the structuring of productive and social interactions. Our approach is in line with some of the work conducted on innovation dynamics in the dairy sector (Torre et al., 2019; Pachoud et al., 2019), the evaluation of farmers' collective agroecological practices (Houdart et al., 2011), local governance and rural development arrangements (Polge and Torre, 2017), and the importance of governance arrangements for the implementation of circular economy strategies in territories (Jambou, 2018). Eventually, we want to test the hypothesis that the mobilization of various types of proximities could help to build a strong local network between local producers, customers, authorities and association of local residents.

We first present the SMPF AD project, then the theoretical

framework and methodology used to analyze the territorial governance of this case study. Based on our surveys, we study the technical and innovation trajectories and their evolution at the local level, representing them in the form of flow networks. We then analyze the dynamics of the social networks, which reveal the evolution, over time, of synergies and cooperative behaviors among the actors of the Cavigny AD. The last part is devoted to analyzing the importance and role of proximity relations in the productive choices and relations maintained by the actors of this process.

## 2. Site description and research method

### 2.1. Case study: the SMPF of Cavigny (France)

The Syndicat Mixte du Point Fort (SMPF) is a public establishment of inter-municipal cooperation (EPCI), which ensures the prevention and management of waste from 125 municipalities—including one agglomeration—located in the Department of Manche, in the Normandy region (France). It is situated in Cavigny, a small rural municipality of 257 inhabitants, and directly connected to a main road (2 × 2 lanes), facilitating the arrival of trucks bringing household waste. It organizes selective collection (packaging, paper, glass), carries out pretreatment, and eliminates and treats waste. In 2019, 116,744 inhabitants, representing 23% of the department's population, were concerned by its activity (Point Fort Environnement [PFE], 2020).

Each member community of municipalities is represented in the SMPF by one or more delegates, who make up the syndical committee. This is composed of 38 members who vote on the budget and decide on the main orientations during the deliberative assemblies. The members also elect the Executive Board (BE-SMPF), made up of the President and eight Vice-Presidents. The technical department—PFE—is the operational body in charge of the construction and operation of the waste pretreatment and treatment facilities.

The facilities are located in different municipalities of the SMPF territorial perimeter (Fig. 1). The 14 waste collection centers are accessible free of charge to the inhabitants and technical services of the member municipalities. It should be noted that certain non-member municipalities, in partnership with PFE within the framework of agreements or public contracts, bring additional tonnages to the SMPF, enabling it to make the AD facilities profitable. In addition to the 14 waste collection centers, two transit platforms for glass and a non-hazardous waste storage and burial facility (ISDND) with a capacity of 70,000 tons are also available. Finally, to reduce the fermentable part of the organic matter to be buried, and thus to limit leachates (waste juices), in 2009, the SMPF equipped itself with a sustainable treatment plant to valorize its waste. It is located in Cavigny and includes several facilities, including a modernized sorting center and an AD unit.

With a capacity of 72,000 tons per year, the AD unit treats the organic fraction contained in household waste and shredded green waste (grass, leaves, wilted flowers, etc.) from waste collection centers. These are transformed into biogas and compost, intended for reuse in the form of heat, electricity, and nitrogenous organic fertilizer. The creation of this biogas plant responds to the will of local authorities with regard to developing the circular valorization of organic waste into territorial resources, promoting the local use of renewable energy, and practicing reasoned agricultural fertilization. It thus contributes to ensuring local energy autonomy, savings on energy and nitrogen fertilizer (Holm-Nielsen et al., 2009), and reducing diffuse pollution (air, water, and soil) and GHG emissions. It also allows the creation of non-relocatable values and jobs (Guenther-Lübberts et al., 2016).

The process offers both an example of the valorization of organic waste into local territorial resources and of innovation and cooperation dynamics between actors based on the circular economy chain. It brings together different stakeholders, consisting of local authorities that provide the inputs (waste), public companies that manage the waste and co-products, and farmers who use the compost. The departmental technical

services intervene in the inspection of the process and the operation of the AD unit, an installation classified for environmental protection (ICPE). They monitor potential negative externalities that could impact local populations and residents. The residents' association "Vivre au pays de Daye" is associated with this process within the regulatory monitoring commission for risks and negative externalities, which gives local populations access to a certain amount of information and control over decisions (Kortsch et al., 2015).

Within the framework of the practices and exchanges within this AD process, new social relations are created and developed between the people and the organizations at the origin of the material and energy exchange flows. This mechanism of territorial governance is essentially based on the consultation and information exchange mechanisms set up within the SMPF and the site monitoring commission and on the contractualization with the stakeholder clients.

### 2.2. Study methodology: social networks and proximity relations

The objective of our study is to analyze the collective dynamics of the stakeholders of the Cavigny SMPF to account for the interactions that characterize the types of exchanges within the AD process. The research thus targets the different links (social, economic, and geographical) created and developed between actors with different functions and belonging to different territorial scales. To grasp the process of the construction of collective action and the associated governance mechanism, we mobilize a theoretical framework combining the relational approaches of social networks and proximities. We begin by studying the networks of actors and their structures to describe the hierarchy of interaction relationships and the role and place of each actor in the coordination process (Crona et al., 2011). We then analyze how proximities between stakeholders are organized and modified to better understand the process of collective action and the link between the structuring of networks, the quality of interactions, and their organization around pivotal actors (Torre et al., 2019; Pachoud et al., 2019).

The social network approach, based on graphical visual analysis and statistical measures of interaction relationships, is based on relational data (Wasserman and Faust, 1994). We use primary information collected between April and August 2019 through 27 semi-structured interviews with representatives of different categories of local actors.<sup>1</sup> The interview guide developed for this purpose was intended to identify all the information that could reflect the network structure's overall and local sociometric characteristics. The people to be interviewed were identified during an exploratory interview with the project management team during which all the categories of actors and types of exchanges of material and energy flows and information and communication relationships were considered. In addition, using the "roster-recall" method (Ter Wal and Boschma, 2009; Wasserman and Faust, 1994), the interviewees were asked to qualify the relationships maintained with the other participants in the innovation and governance dynamics of the AD flows. Each actor involved in the AD project was thus able to list the participants with whom he or she maintains collaborative relations, while describing the nature and form of these relationships. Therefore, if some key actors had not been identified in the exploratory interview with the project management team, the other interviews conducted with the other actors allowed us to identify some other actors, allowing us to have a comprehensive view of the project stakeholders.

The analysis was carried out over the entire development period of

<sup>1</sup> Note that the data for analyzing the evolution of the network, i.e., information about the links at different times, was collected at a single point in time. In fact, this poses a "recall bias". Respondents may not remember well what their connections were in the past. Therefore, analysis of our data and the evolution of networks collected in this way must be done with caution. A more ideal method would have been to conduct interviews with all actors at different points of time in the project to limit any recall bias.

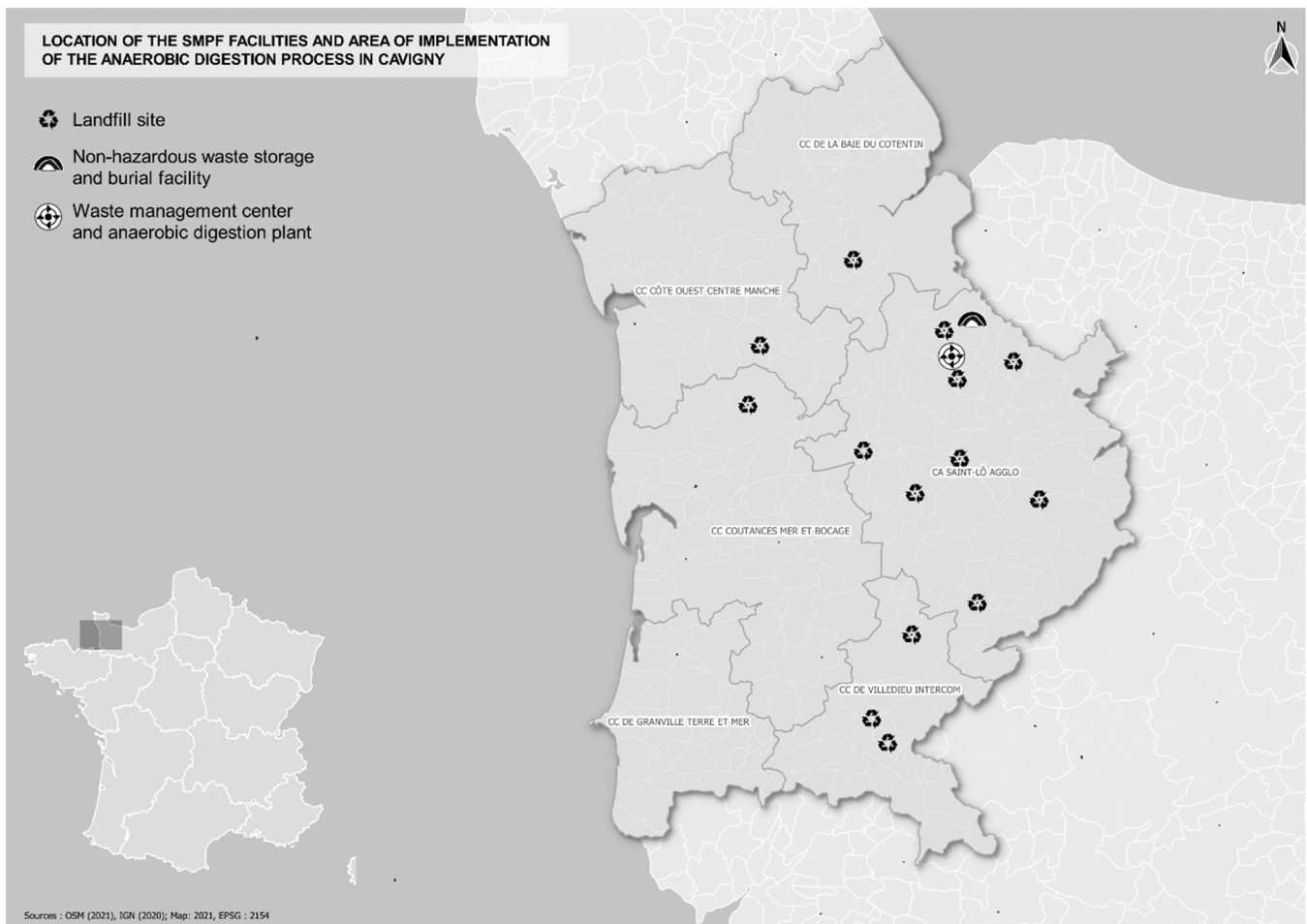


Fig. 1. Location of the SMPF facilities and territory of implementation of the AD process in Cavigny.

the AD project and divided into three key stages: 2010, 2015, and 2020. This chronological aspect of the evolution of the networks makes it possible to appreciate the conditions of the creation and renewal or disappearance of the synergy relations between actors. The analysis for 2010 and 2015 was carried out based on the relational data from the reconstruction of the history of interactions (Grossetti et al., 2011) from interviews with former SMPF managers and employees present since the beginning of the AD project. With these interviews, we gathered additional information on the actors entering or leaving, actions, and controversies that marked the local context of the development of the AD project in Cavigny.

The data—organized in a matrix form to define the links between the actors for each type of exchange—were then processed using NetDraw software to represent network graphs and Ucinet to perform statistical measurements. We thus estimated the potential for synergistic relationships within the networks by the density of the links. We detected cohesive subgroups (n-cliques)<sup>2</sup> that express references to the mental adhesion to the project (relative to their cognitive or cultural references) of the actors who gather and work together on common challenges (Borgatti, 2002). The estimation of these characteristic indicators of

<sup>2</sup> The n-cliques expressed as the number of sub-groups observable within the network, make it possible to identify cohesive groups of actors who are strongly linked to each other, as well as the potential relay actors (intermediaries). They provide the links between the sub-groups. The presence of many n-cliques implies a weakness of relations between actors, resulting in a non-cohesive network. In contrast, a limited number of n-cliques is synonymous with solidarity, social control and information circulation.

structural properties was complemented by the degree centrality measure to analyze the influence of each actor in the synergy relationships (Crona et al., 2011).

In order to understand the modalities of the emergence of collective action and the dynamics of social and economic ties that are created and strengthened or unravelled over time (Lazega et al., 2015), we then proceeded to study the coordination structure. We analyzed the proximity relations between actors and their evolution (Torre et al., 2019; Polge and Torre, 2017). This made it possible to interpret the results obtained in terms of social networks and, in particular, to specify the nature of the interactions and provide a better understanding of the actors' structuring and governance mechanisms at work in the AD process. The analysis of the characteristics of the interactions that make up the networks using a qualitative approach allows for a better understanding of the logic of collaboration between actors and the potential for conflict or opposition, as well as the role played by the different categories of stakeholders (Torre, 2014).

We distinguish here, in a classical way (Torre and Rallet, 2005), two main categories of proximity. Geographical proximity, linked to spatial and distance dimensions, can facilitate productive collaborative relationships and local stakeholders' participation and provoke opposition to AD projects from local populations. Its permanent form can facilitate direct contact and the exchange of flows between actors located in nearby territories or be the source of conflicts that block local collective dynamics (Magsi and Torre, 2015). It takes a temporary form in the case of occasional meetings between actors, facilitated by their movements. Organized proximity refers to the actors' membership in an organization or social network (logic of belonging) or their mental adhesion to the

project (see above) (logic of similarity). It determines and explains collective action strategies, which are the result of social interactions between actors of all kinds and result in cooperative relationships or bonds of trust (Dupuy and Torre, 2006).

### 3. Results

#### 3.1. Exchanges on the technical and innovation trajectories at work at the local level

The interviews with the stakeholders of the Cavigny AD process made it possible to highlight the dynamics of material flows within the local eco-industrial system. They revealed the relationships maintained in terms of productive exchanges of materials and energy (waste, electricity, and compost) (Table 1). The five categories of productive actors (Member municipalities, SMPF, Customer municipalities, Compost customers (farmers + firms)) identified coordinate with regard to the issues of input mobilization, co-product disposal, risk management, and the social acceptability of the AD project. It is on this basis that the local recycling and innovation mechanism is set up.

These issues result from a dynamic productive and territorial partnership involving local authorities (communities of municipalities) that collect household waste and entrust its treatment and recovery to the SMPF. In a commercial approach, the latter also draws up contracts with client communities for the treatment of their waste. The co-products are intended for a triple energetic and agronomic reuse in heat, electricity, and organic nitrogen fertilizer. The heat (produced by the combustion of part of the biogas) is reused on site for the operation of the digesters, while the electricity and compost are marketed by two of the SMPF's client companies. Within the framework of a contract established based on a regulated price, the electricity produced by the cogeneration of the biogas is repurchased by the public energy supplier. The compost produced, called "Fortisol," is sold to another public company and then purchased by farmers, who use it on their farms as organic fertilizer.

The material and energy exchange network analysis reveals the multi-actor mechanism of production dynamics and its evolutionary trajectories in 2010, 2015, and 2020 (Table 2). The relationship graphs (Fig. 2) reveal the relationships between (i) the territorial authorities (members and non-members) providing inputs, (ii) the SMPF bodies and establishments managing the waste, and (iii) the companies and farmers specializing in the valorization of co-products. Since the decentralization law of 2015, the "competence of household waste treatment" is ensured at the level of the groupings of municipalities, instead of at the level of the municipalities. This may explain why there is a decrease in the number of relationships within the recycling stream network.

On the other hand, their density remains high throughout the

**Table 1**

Categories of material and energy exchange relationships maintained by the AD stakeholders in Cavigny.

Relation categories		Actors involved	Participation
Productive economic cooperations	Collaboration on sustainable waste management	Member municipalities	Collection and disposal of household waste
	Commercial (prospecting and canvassing of client communities)	SMPF	Management, treatment, and recovery of household waste
		Customer municipalities	Waste disposal based on partnership agreement and public market
		Professional customers of the valorization of co-products (firms and farms)	Purchase and resale of electricity and compost (reuse)

development period, decreasing in 2015 to increase sharply again at the end of the period, resulting in more than half of the possible social links. Only two cohesive (2, 2 cliques) and interdependent subgroups are in productive interaction during this period of evolution and development of the project. They are composed of all the actors in the methanization value chain, apart from farmers (AgrP1) and the company that markets the energy (EntrP2) which each interacts in a single subgroup. The high density of the networks and the very limited number of n-clicks are indicative of the strong group cohesion in the exchanges of economic flows. However, the average number of links involving each actor in the networks (average degree) which continues to decrease, despite a high value at the beginning of the period, indicates the loss of cohesion in the evolution of material and energy exchange relationships.

The average degree value for each category of actors (Table 2) is represented in Fig. 2 by the size of the nodes in proportion to their centrality value. This indicator shows that the organizations of the SMPF that carry the project are the central actors of high degree values, having the most important number of productive interactions. They are composed of the landfills and the operational management of the SMPF which ensures the coordination of waste collection and the distribution of co-products, as well as the management of the networks of actors. This task has been ensured and maintained over the 2010 and 2020 period.

#### 3.2. The social links maintained by the AD actors

The partnership model of industrial AD, which involves many actors, is characterized by different categories of innovations (Mol, 2014). These include biotechnological innovations in terms of production processes and innovative products and organizational innovations, which allow the participation of all stakeholders in the governance of the project and play a decisive role in the social and economic links thus created. The networks of interactions and exchanges of information between participants in the Cavigny AD process reflect these governance modalities and the exchanges of information and cooperation processes at work at the local level.

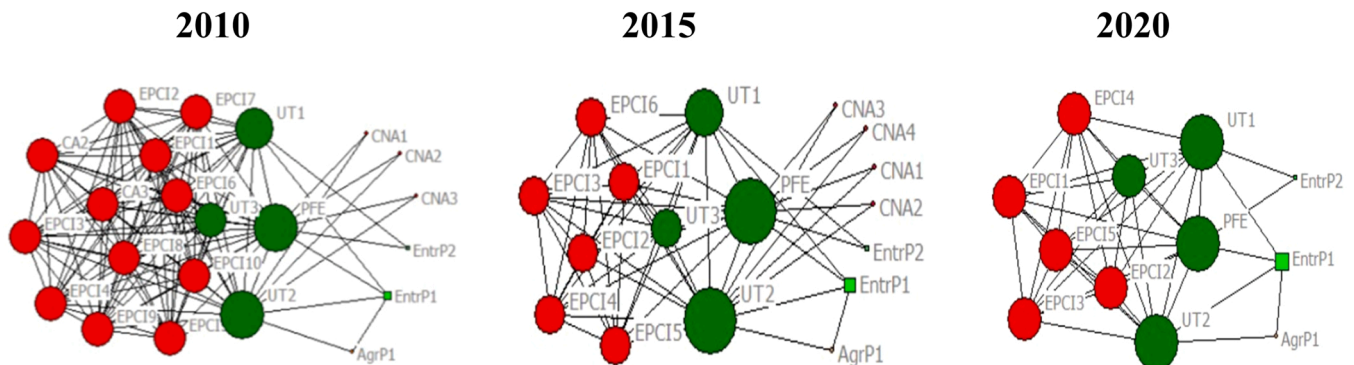
Interviews with stakeholders in the AD process revealed information exchanges and collective activity carried out within communication relationships. We were able to identify the circulation of flows and the network of exchanges in terms of communication, which involve both the local authorities and municipalities associated with the project and the decision-making bodies of the project leader (PFE and BE-SMPF). Interactions within the network occur in different ways: through dialogue and consultation during the meetings of contacts and deliberative assemblies of the SMPF member communities and through the regulatory meetings of the site monitoring commission placed under the responsibility of the administrative authorities (Table 3).

These shared and concerted governance bodies include the issues of profitability and the social acceptability of the project in the circulation of AD flows. They represent a framework for exchanging best practices and information on the process, the mobilization of inputs, and the management of environmental externalities, nuisances, and risks. Apart from the SMPF's non-member local authorities and client companies, all the participants are involved in the process, including the residents represented by the "Vivre au pays de Daye" association. For example, during these formal meetings, SMPF managers explain (i) their controlling of the AD process to identify and correct any malfunctions and (ii) compliance with safety standards and measures, as well as (iii) the samples, measurements, and analyses carried out periodically by the public technical support services. The local residents' association also holds bi-weekly meetings with the SMPF to discuss, in particular, the odors, health risks, and traffic resulting from the trucks bringing in the biomass.

To define these information exchange and communication networks, we considered the interactions resulting from exchanges in communication between representatives of the structures and organizations involved in the AD process. They correspond to the bulk of the face-to-

**Table 2**  
Structural characteristics of the AD material and energy exchange network.<sup>31</sup>

Indicators		2010	2015	2020			
Network Size	Nr. of actors	22	17	12			
	Nber of links	266	120	86			
Network Structure	Density	0.576	0.441	0.652			
	Average degree	12.091	7.059	7.167			
	N-clic	2 2-clics	2 2-clics	2 2-clics			
	<b>Categories of actors: proportion (%) &amp; average degree</b>						
Network Composition	Member municipalities	54%	15.71	35%	9.56	42%	8.72
	SMPF	18%	20.95	24%	15.94	33%	10.90
	Customer municipalities	14%	2.10	24%	2.12	–	–
	Compost customers (farmers)	5%	2.10	6%	2.12	8%	2.18
	Co-product customers (firms)	9%	4.19	11%	4.25	17%	4.36



**Fig. 2.** Evolution of the material and energy exchange network. **Legend:** The nodes of the networks represent the actors, the arcs their relationships, and the shape of the nodes corresponds to the scale of action of the actors (the circle at the local level, the triangle at the departmental level, and the square for the national level). The size of the nodes represents the number of relationships involving an actor in proportion to its degree value, and indicates the influence and importance of actors in the innovation mechanism and the governance of AD flows. ● SMPF waste management bodies and units. ● Local authorities. ● Compost customers (farmers) ■ Co-product customers (firms).

**Table 3**  
Categories of information exchange maintained by the stakeholders of AD in Cavigny.

Relation categories		Actors involved	Participation
Communication	Dialogue, consultation, exchange of best practices, networking	Member municipalities SMPF	Deliberative assembly, union committee (38 delegates), executive board meeting (9 members)
		State technical support services Residents' association	Monitoring and controlling of the facilities, exchange information on the process with the committee

face exchanges that take place in formal relationships (78%) belonging to the SMPF and the site monitoring committee, and only to 7% of informal relationships with customers (see Table 6). Exchanges can be direct, in verbal or electronic form, and be performed once or several times per month. They are essentially carried out within the framework of the economic and commercial partnerships of the actors, even if interpersonal, social friendship, leisure, or family links exist between the individuals. The links created during the three phases of network evolution are listed in Table 4, according to the answers given to the questions asked about the participants' relations at work.

The different exchanges are represented here by their relationship graphs and their evolution and development trajectories in 2010, 2015, and 2020 (Fig. 3). The network of communication relations was slightly denser, especially at the beginning of the period, with a slightly higher average degree of connectivity, suggesting a strong group cohesion in the framework of dialogue and consultation that was consistent with the launch of the anaerobic digestion project. However, its size diminishes

**Table 4**  
Structural characteristics of methanization interaction networks.

Indicators		2010	2015	2020			
Network Size	Nr. of actors	21	15	14			
	Nber of links	286	136	118			
Network Structure	Density	0.681	0.648	0.648			
	Average degree	13.619	9.067	8.429			
	N-clic	2 2-clics	2 2-clics	2 2-clics			
	<b>Categories of actors: proportion (%) &amp; average degree</b>						
Network Composition	Member of municipalities	57%	15.75	40%	9.64	38%	8.61
	Town hall of Cavigny	5%	19.95	7%	13.92	7%	12.92
	SMPF	14%	19.95	20%	13.92	21%	12.92
	State technical support services	19%	7.35	26%	7.50	7	7.53
	Residents' association	5%	8.40	7%	8.57	7%	8.62

**Table 5**  
The relations maintained according to the distance between the actors.

Scale of action	Category of actors	Nber of effective relations			Average Nber of links		
		2010	2015	2020	2010	2015	2020
<b>Material and energy exchange network</b>							
Local (0–45 km)	Member municipalities	180	54	40	11.2	5.4	4.4
	SMPF	61	37	33	3.8	3.7	3.7
	Compost customers (farmers)	1	1	1	0.06	0.10	0.11
	<b>Total</b>	<b>242</b>	<b>92</b>	<b>74</b>	<b>15</b>	<b>9.2</b>	<b>8.21</b>
Departmental (45–100 km)	SMPF	18	17	12	3	2.43	4
	Customer municipalities	6	8	–	1	1	–
	<b>Total</b>	<b>24</b>	<b>25</b>	<b>12</b>	<b>4</b>	<b>3.43</b>	<b>4</b>
Regional or national (+100 km)	SMPF	18	17	17	3	3.4	3.4
	Co-product customers (firms)	6	5	5	1	1	1
	<b>Total</b>	<b>24</b>	<b>22</b>	<b>22</b>	<b>8</b>	<b>4.4</b>	<b>4.4</b>
<b>Exchange network in terms of communication</b>							
Local (0–45 km)	Member municipalities	196	54	40	12.2	5.4	4.4
	Town hall of Cavigny	16	10	9	1	1	1
	SMPF	48	30	27	3	3	3.5
	Residents' association	4	4	4	0.25	0.40	0.44
	<b>Total</b>	<b>264</b>	<b>98</b>	<b>80</b>	<b>16.4</b>	<b>9.8</b>	<b>9.3</b>
Departmental (45–100 km)	SMPF	19	19	19	2.38	2.38	2.38
	Town hall of Cavigny	7	7	7	0.88	0.88	0.88
	State technical support services	25	25	25	3.13	3.13	3.13
	Residents' association	7	7	7	0.88	0.88	0.88
	<b>Total</b>	<b>58</b>	<b>58</b>	<b>58</b>	<b>7.3</b>	<b>7.3</b>	<b>7.3</b>

**Table 6**  
The logic of belonging and the frequency of interactions of organised proximity relations.

	Questions	Variables	Answers	
			Number	%
Synergy (means of communication and frequency of exchanges)	How do you communicate most often with this person?	Most often remotely by phone, email.	4	15
		Most often face-to-face	21	78
		- Formal meeting - Informal meeting	2	7
	How often do you communicate with your partners?	Regularly	9	33
		- Every 2 weeks - 2–4 times/year	16	59
		Very occasional (Annual face-to-face or remote point)	2	7
	In what context did you know partners?	Before the creation of the anaerobic digestion unit	25	93
		Through the anaerobic digestion unit	2	7
	Maintain relationships outside of anaerobic digestion	Family	3	11
		Friendly	7	26
Professional		17	63	

in the following periods due to institutional restructurings and mergers between territorial authorities. While relying heavily on material and energy exchange practices, this network also reveals the importance of organizational exchanges in mobilizing technological innovations.

<sup>3</sup> The average degree represents the average number of links involving an actor. It measures the value of degree centrality which makes it possible to highlight the central actors of the interaction network, having the greatest number of relationships (Freeman, 1979). The higher the degree value of an actor, the more central and active it is within the network, playing an important role in the flow flow (Wasserman and Faust, 1994).

These exchanges are also organized in two cohesive subgroups (2, 2 clicks) of actors developing higher social ties compared to the network of exchanges of materials and energy. These two interdependent n-clicks are distinguished by the participation in the first sub-group of all the actors, except ADEME (SE4) which participates only in the communication sub-group, composed of the members of the site’s monitoring committee (SMPF, Town hall of Cavigny, State technical support services & residents’ association).

The coordination of all partnerships is organized around the project leader (the SMPF), which plays the role of assembler and animator of the networks. It facilitates the circulation of flows by jointly occupying intermediation functions, thus ensuring a role of relay between the central actors with high degree values and those who have fewer links with them (see Table 4). However, it should be noted in these networks of communication relations that the town hall of Cavigny, which hosts the AD facilities, joins with the SMPF’s executive office to ensure the function of territorial intermediation. By maintaining communication relations between the stakeholders, these actors guarantee the effective mobilization of material resources to make the installations profitable and prevent possible conflicts or opposition to the project. This result confirms Bourdin and Nadou’s (2020) work on the fundamental role of territorial intermediation, which the owner of an AD project must fulfill.

We also note that the role of the local residents’ association has increased steadily since the implementation of AD in Cavigny due to its strong involvement in the regulatory governance of the project. It is involved in the reflection and dissemination of information, allowing the local population to participate in the steering of the project and helping to calm local conflicts. The importance of its role results from the position it holds as an ex-officio member of the site monitoring commission and from its periodic contact with the members of the SMPF during deliberative assemblies and informal meetings, which allows it to communicate with almost all the stakeholders of the AD project.

### 3.3. Proximity links of the AD actors

We now turn to the analysis of proximity relations, which allows us to complete the study of productive and communication interactions in the governance of AD flows and determine the main motivations of the actors and the constraints they face. The application of the proximities analysis grid to the network approach results allows us to better understand the emergence and deployment modalities of the governance

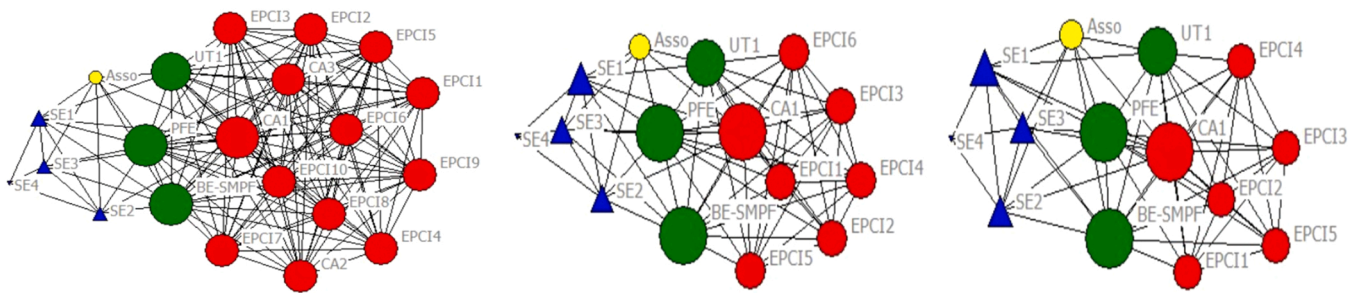


Fig. 3. Evolution of the exchange network in terms of communication. Legend: The characterization of the nodes and arcs is the same as in Fig. 2. ● SMPF waste management bodies and units ● Local authorities. ▲ State technical services ● Residents' association.

process and the possible obstacles to its development. It appears that the multidimensional nature of the structure of the Cavigny AD network leads to collective action and makes territorial innovations possible by allowing the activation of different types of proximity links between local actors and obstacles to be overcome that may arise from these same proximities. Territorial innovations depend heavily on proximity (geographical and organized) relations, which play a determining role in the technical, social, and economic links at work between local actors (Torre and Rallet, 2005).

### 3.3.1. Geographical proximities that strengthen local ties

The relationship between the SMPF and the local authorities that bring in household waste is based on permanent geographical proximity. The environmental center in Cavigny, where the AD unit is located, is situated at the crossroads of the local authorities that are members of the mixed syndicate. Similarly, the 14 waste collection centers that collect and transport green waste are also located nearby. This co-location ensures a territorial network of waste treatment and production facilities, reinforced by transport access. The center is directly linked to the departmental road network via the D974 road from the Porte Verte interchange, facilitating access for trucks bringing in waste and removing compost. Other client communities not belonging to the mixed syndicate also bring waste to be treated (BCEP, 2019).

Table 5 shows that the technical, social, and economic relationships are essentially concentrated at the level of the territory of the mixed syndicate's jurisdiction, between the communities that supply the waste, the SMPF in charge of the recovery and the farmers which reuse the compost. This geographical proximity was sought by the actors. It allows them to meet more often to boost the governance of flows (Torre and Wallet, 2014) and restricts the extent of the circulation of the latter, contributing to the sustainability of the AD process. It contributes to the mutualization of transport, sorting, treatment, and waste recovery functions, which reduces transport and transaction costs. Finally, it strengthens the links and exchanges while ensuring the junction between the competencies of the collection of waste devolved to the municipalities and that of its treatment by the mixed syndicate. It should be noted that most of the actors interviewed during our study who are involved in the process consider themselves to be geographically close to their partners.

Geographical proximity is also sought for its benefits upstream of the process. The farmers who buy the compost are located within a 30 km radius of Cavigny. In addition, despite the national dimension of their activities, the companies in charge of marketing the co-products are keen to be present at the local level. They come on site when necessary to respect the contractual commitments within the commercial exchanges of the AD products. For these companies, we can speak of temporary geographical proximity.

This diversity in the scales of actions and links testifies the relevance of the intermediary role played by the SMPF managers, who implement

networking and facilitate the bringing together of stakeholders by activating geographical proximity. Geographical proximity thus constitutes a factor of territorialization and the local anchoring of the AD project and plays a major role in the process of territorial governance. The raw material for production, which is renewable, is locally available, and the consumption of the products is carried out at the local level.

These different elements indicate the interest of the geographical dimension of proximity in the valorization of waste and the creation of added value anchored in the territory. However, when it is sought for its benefits, it becomes potentially conflicting when certain categories of actors experience it. Thus, even before the AD facilities were set up in Cavigny, the SMPF faced opposition from the local population, which was concerned about the risk of explosions, as well as environmental damage, possible noise or odor pollution, and pollution linked to the increase in traffic. This is a typical case of unwanted geographical proximity, which is in line with various studies that have highlighted local resistance to AD projects, resulting in the emergence of attitudes of rejection (Soland, 2013; Bojesen et al., 2015; Schumacher and Schultmann, 2017; Giuliano et al., 2018; Bourdin et al., 2020).

In a study in Denmark, Zemo et al. (2019) showed that the size of AD projects negatively influences residential property values, putting such sites at risk of downgrading. Magsi and Torre (2015) pointed out that geographical proximity brings conflicts (regarding the neighborhood and use) and that the mobilization of organized proximity allows them to be anticipated and resolved to some extent (Torre & Zuindeau, 2009). This position is illustrated by the choice made locally to include the local residents' association, "Vivre au pays de Daye," in the debates and deliberations of the group of institutions involved in the AD process in Cavigny. It contributes greatly to the reduction of opposition and the limitation of possible conflicts created by the development of this activity.

Taken together, these elements reveal the extent to which geographical proximity plays an important role in the territorial governance process. Important in two ways. First of all because geographical proximity provokes local opposition to the installation of the AD, following the fears and the opposition of the local populations. But also because it contributes to the setting of harmonious relations between the various stakeholders involved in the production process, the consumption and recycling of waste. Thanks to temporary and permanent geographical proximities, both physical and organizational relationships are facilitated and streamlined along the local loop. From this point of view, this confirms the importance of geographical proximity and the local anchoring of actors to facilitate their coordination and the success of a project.

### 3.3.2. Organized proximities that allow for collective action and conflict management

Organized proximity is based on two types of logic: belonging and



similarity (Torre and Rallet, 2005). In the governance of the Cavigny AD project, the logic of belonging is expressed by the fact that certain local authorities associated with the project belong to the mixed syndicate, which is where most of the exchange relations are concentrated in terms of production and communication. The interactions between the members of the SMPF are carried out through dialogue and consultation within the PFE. This body makes decisions on strategic orientations and plays an essential role in the governance of AD flows. It facilitates direct contact between the communities and the technical department responsible for coordinating the operational implementation of the project.

The logic of belonging is also at work in the relation networks of the actors in the AD value chain, for example, between the producers of waste and by-products and the users of these resources. Our interviews show that the central actors exchange information regularly, often through face-to-face meetings of an informal nature. These meetings take place every 15 days or so, or more regularly, and are supplemented by telephone exchanges, which help to densify and solidify the network. For the others, it is most often telephone contact with the same frequency. The project leader facilitates these interactions (the SMPF) and acts as an intermediary to guarantee social links between actors, particularly with client communities and companies. In particular, its work contributes to facilitating the sharing of knowledge flows and collective learning with the deconcentrated services of the State, co-product professionals, and communities that are not members of the materials and energy exchange network (see Table 6).

The fact of belonging to the same network is often based on similar characteristics of the actors, and thus on relations based on the logic of similarity of the organized proximity. In the case of the Cavigny AD project, the stakeholders share a sensitivity to the environmental values of the ecological and energy transition. They gather around a common ideal, which allows for the local and circular production and consumption of renewable energies from municipal waste and the practice of sustainable agricultural fertilization (Table 2). For example, companies specializing in the distribution of co-products are now privileged interlocutors for implementing national AD policy. In doing so, they also contribute to the sustainability of the territorial development process.

In order to underline the importance of the logic of belonging, it should be noted that all the actors involved in the process knew each other beforehand, often through their waste management activities. Furthermore, the establishment and operation of local bodies, such as the SMPF, contributed to strengthening the sense of community, based on the interpersonal social ties that are created and developed, and made it possible to establish a climate of trust and consultation between the producers and waste managers. This involves creating bonds of similarity, which contribute to the creation of a relational context favorable to the cooperation and coordination of actors (Dupuy and Torre, 2006).

The trust created between production actors is thus based on articulation between logics of belonging and similarity. Still, it also depends on the integration of conflicting potentialities concerning other local stakeholders (Soland et al., 2013). Trust in the SMPF has fostered the social acceptability of the project. This was created from the project's inception through moments of exchanging information between local elected officials and the population, which adhered to the sustainability values of AD. The transparency of the choice of the Cavigny site and the administrative procedure for its implementation, and the possibilities for stakeholder participation in the management of the territorial project (Kortsch et al., 2015; Bourdin and Nadou, 2020), helped to prevent conflicts and ease tensions.

Far from being a hindrance to the development of the project, the discussion around the siting of the AD unit has become a source of organizational innovation. The local population has organized itself within the “Vivre au Pays de Daye” association. Alongside the State's technical services, it is involved in the regulatory governance of the risks of AD. This is a solution already presented by Soland et al. (2013) in the

case of AD installations in Switzerland. This framework for dialogue and consultation, set up before the start of the project, has also made it possible to disseminate information and knowledge, creating a feeling of public support for the AD project. The mechanism has now been extended within the site monitoring commission as part of the regulatory governance of risks, enabling relations of trust to be maintained.

Thus, the mobilization of organized proximity relations has made it possible to contribute very effectively to the setting of a virtuous territorial governance process, in two ways. Firstly, by making it possible to solve the problems posed by the geographical proximity of populations (NIMBY effect); the relations of organised proximity have made it possible to initiate a fruitful discussion and exchange between the participants in the AD process and the residents of the neighbourhood, in particular by the creation of a local association and the action of the public authorities. The setting up of forums for discussion and consultation contributed to the success of the methanisation process. But organised proximity has also played an important role between producers, consumers and public authorities during this process: it has helped them to discuss and to overcome their misunderstandings and technical obstacles. It has enabled the survival and the growth of the local circular economy loop through their mutual knowledge and the many exchanges of all types that have animated them, and in particular to overcome the difficulties caused by the territorial reforms and the subsequent merging of activities.

#### 4. Conclusion and policy implications

The circular economy and the energy transition, which are now in the spotlight with regard to the fight against climate change, are also part of a territorial dynamic that brings together multiple actors or local stakeholders from a wide variety of backgrounds. They thus appear as important elements of local solutions to global change and as contributions to sustainable territorial development processes. Our analysis of the installation and development of the AD process in the case of Cavigny, France, aimed to examine how the mobilization of different types of proximity contributed to the creation and perpetuation of a sustainable solution based on the agreement of all stakeholders in the territory, whether producers, local authorities, or local populations.

The analysis of social networks has made it possible to highlight both the flow of materials and exchanges in terms of communication. In particular, it has highlighted the importance of governance mechanisms in the implementation of this technological innovation in the territories. The results show the role played by the interaction and coordination structure of the stakeholders, which goes beyond the exchange of flows and also concerns the way in which the actors collaborate or work together in order to combine their plans and strategies. We also highlight the role of communication exchanges in the structuring of productive exchanges (Rosado et al., 2014) and the interest provoked by an approach focused on social ties in understanding industrial metabolism processes (Walls and Paquin, 2015).

The analysis of proximities shows that all actors are in a situation of close permanent geographical proximity, which facilitates links and exchanges between waste and by-product producers, on the one hand, and their users as a resource, on the other, as well as with the responsible territorial authorities. But, this proximity also produces negative effects linked to the initial opposition to the project from populations because of the perceived risks, which cause tensions. However, this opposition can be resolved by integrating citizen stakeholders into the decision-making process and the evolution of the AD project. The resources of organized proximity can then be mobilized to serve organizational innovation, in particular, through local residents' associations and their participation in territorial governance.

In addition, the collective action between producers or users, built progressively over time, was observed to be largely based on the resources of organized proximity, within its two dimensions of belonging and similarity. Relationships of similarity, particularly around

environmental values, make it possible to forge and solidify local networks around shared values. Relations of belonging are subsequently created through working together and sharing objectives; they are solidified and intensified through repeated exchanges between participants, whether face-to-face or by telephone. This increase and solidification of relations of organized proximity explain the persistence of interaction synergies and the maintenance of the dynamics. It also allows the success of a circular process during a decade that has been strongly marked by territorial reforms, which could have destabilized this ensemble due to the merger processes and the change of institutional actors in charge of operations.

All in all, and at the local level, it is clear that the intersection of geographical and organized proximity favors both the birth and stabilization of territorial governance processes. From this point of view, coordination between actors and the involvement of all stakeholders is

fundamental. The joint mobilization of proximities greatly facilitates the implementation of the AD project and its sustainability and the modes of organization of local stakeholders of all kinds, from producers to associations, including public authorities and territorial communities. The model of sharing and exchange put in place goes beyond technical considerations. It participates in creating a local territorialized economy, which reveals the importance of the various categories of proximity in the local valorization of waste and the creation of added value anchored in the territory.

**Declaration of Competing Interest**

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

**Appendix 1. The variables studied**

Variables	Means of mobilization	Measurement measures
Collaboration	Type of collaboration (joint project, collective meeting) Number of exchanges, contacts	Do you work or have you ever worked in collaboration with this actor? Has the intensity of the relationship changed since the start of the AD unit?
Geographical proximity	Location of facilities Perception of the geographical distance separating the actors in space	How far away (in km) are you from this actor or equipment? In terms of geographical distance, do you consider yourself close or far away?
Organized proximity	Frequency of telephone or e-mail exchanges  Belonging to the same organization, the same network	How do you most often communicate with this person? (face-to-face, telephone.) How often do you communicate with this person? Did you know this company or person? Did you have a relationship with this actor? Where did you meet this person?
	Mental and cognitive adherence to the process	In your opinion, what are the results of these actions in terms of the values to which you adhere?

**Appendix 2. : The perception of geographical proximity relations**

	Questions asked	Variables	Answers	
			Number	%
Perception of the geographical distance separating actors in space	At what geographical distance (order of magnitude in km) are you located from a particular actor or equipment?  In terms of geographical distance, do you consider yourself close or distant?	0–20 km	13	48
		20–45 km	7	26
		45–100 km	5	19
		+ 100 km	2	7
		Near	22	81
		Far	5	19

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