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An Integrated Approach to Livestock Farming Systems' Autonomy to Design and Manage Agroecological Transition at the Farm and Territorial Levels



Marie-Angéline Magne, Guillaume Martin, Marc Moraine, Julie Ryschawy, Vincent Thenard, Pierre Triboulet, and Jean-Philippe Choisis

Abstract In agroecological approaches, autonomy emerges as a central concept. It is also meaningful for farmers, for whom implementing the agroecological transition of livestock farming systems (LFS) requires greater autonomy with respect to inputs and the dominant socio-economic and technical regime. How does this concept of autonomy encompass the complexity of the agroecological transition? This chapter provides an answer through an overview of the various approaches used to analyse the autonomy of LFS, as well as a conceptual framework that can serve to comprehensively examine it. Three approaches to LFSs' autonomy are presented, based on whether they are focused on the flows of material between system components, on the functioning and management of the system, or on the socio-economic organisation and the values underpinning it. Each of these addresses autonomy in its biotechnical or decisional dimension, as well as in terms of three analysis components: embeddedness, dependency, and footprint. The conceptual

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framework inter-relates these two dimensions and three components, thus providing an integrated approach to LFSs' autonomy. Its application to two case studies, one on the farm level and the other on the farm and territorial levels, demonstrates its relevance to design and implement the agroecological transition of LFSs.

Introduction

Over the past decades, the industrial livestock farming model has enabled a massive increase in agricultural production through: (i) animals and plants selected on the basis of their high production potential; (ii) the use of synthetic inputs that minimise the effect of production limiting factors and environmental heterogeneity; and (iii) the standardisation of modes of production and the specialisation of farms and regions. Today, the limits of this model are well-documented (Brussaard et al. 2010; Duru and Therond 2015). Among them are a loss of biodiversity, including agrobiodiversity (i.e. crops and livestock), negative impacts on the environment (pollution, climate change, exhaustion of fossil fuels and water resources), and ethical issues related to the lack of consideration of animal well-being on livestock farms (Clark et al. 2016). All these elements call into question the relevance of the industrial animal production model for the future. In this context, a major challenge for livestock farmers is to simultaneously contribute to the food and nutritional security of humanity, based on limited resources, all the while reducing the negative impacts of agriculture on human health and the environment, and maintaining decent living conditions. Many researchers believe that agroecology is a promising way to overcome all of these challenges (Dumont et al. 2014; Altieri et al. 2017).

As a scientific discipline, agroecology is defined as “the application of ecological concepts and principles to the design and management of sustainable agroecosystems” (Altieri 1987; Wezel and Soldat 2009; Duru et al. 2015). This definition emphasises the fact that natural processes, and in particular biodiversity and the interactions between biotic and abiotic elements, can support the sustainability of livestock farming systems (LFSs) and enable production at adequate levels while simultaneously reducing dependency on agricultural and agrochemical inputs, as well as negative impacts on human health and on the environment, even under sub-optimal conditions. Francis et al. (2003) define agroecology on the level of the food system as a whole as the integrative study of the operation of the entire food system encompassing ecological, economic, and social dimensions. This definition highlights the transdisciplinary nature of agroecology and the fact that transformations on the farm level are the result of or trigger transformations upstream and downstream of the farm. In line with this, some authors stress the need for farmers to rediscover the sovereignty of their food production, technological, and even energy system (Rosset and Martínez-torres 2012; Koohafkan et al. 2012; Altieri et al. 2017). Within these different perspectives of agroecology, a common and central concept emerges: that of autonomy. The agroecological transition (AET) of farming systems, and in our case, LFSs, would thus take place through a quest for autonomy in terms of inputs, as well as the reconfiguration of the decisional

autonomy of livestock farmers with respect to the socio-economic and technical regime within which they evolve. Addressing the AET of LFSs through the concept of autonomy makes sense for actors in the field (livestock farmers, advisers, etc.). Many livestock farmer networks are seeking to develop LFSs that are self-sufficient in terms of inputs or which use them in small amounts only (Brocard et al. 2016).

In research on livestock farming autonomy, studies focus on improving the feed self-sufficiency of herds, defined as the ratio between the feed produced on the farm and the feed consumed by the animals of this farm. It is expressed in terms of mass autonomy (based on the amounts of dry feed materials, fodder, and concentrates), energy autonomy (based on the amount of energy provided by these foods, expressed in feed units for milk or meat production), or protein autonomy (based on the amount of protein provided by these foods, expressed in total nitrogen). Other studies focus on integrating crop and livestock farming as a pathway to designing livestock farms that are more self-sufficient in terms of feed and use fewer agrochemical products. These studies inter-relate different spatial levels – the farm and the territory – to improve LFSs' autonomy (e.g. Moraine et al. 2016; Ryschawy et al. 2017). Focused on the biotechnical dimension of autonomy, they show that the individual and collective decisional dimension constitutes an impediment to integrating crop and livestock farming, and draw support from participatory processes aiming at overcoming this. Therefore, in the literature, it is clear that LFSs' autonomy: (i) can be understood in its biotechnical or decisional dimensions; (ii) is achieved through the use of local resources and would require the cooperation of actors in the sociotechnical system; and (iii) can be analysed according to different approaches focusing on flows of materials between system components, the functioning and management of LFS, or the organisation of activities around it. Autonomy is therefore a complex topic that it is necessary to understand comprehensively in order to support the AET of LFSs. The goal of this chapter is to give a brief overview of the different approaches to the autonomy of LFSs and to develop a framework to comprehensively analyse it (Section “[Framework to analyse the autonomy of farming systems](#)”). We apply this conceptual framework to two LFS case studies, one on the farm level and the other on the farm and territorial levels. The intention is not to demonstrate that the case studies encompass all elements of the framework, but rather to show the utility of the framework for critically analysing studies on LFSs' autonomy, and for identifying lines of research to complete them (Section “[Case study 1: a methodology to analyse the overall autonomy of dairy sheep farms in Aveyron](#)”).

Framework to Analyse the Autonomy of Farming Systems

Based on the framework proposed by Madelrieux et al. (2017) to analyse agricultural activity as a function of its interactions with the territory, we are developing a framework to analyse LFSs' autonomy that considers biotechnical and decisional dimensions through three analysis components (Fig. 1):

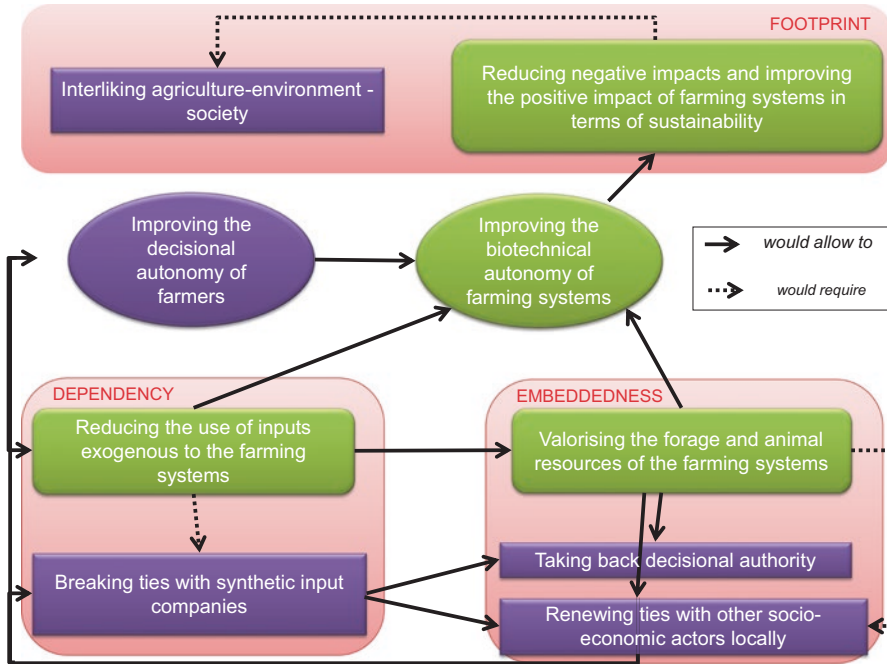


Fig. 1 Conceptual framework for analysing the autonomy of LFSs. It integrates the biotechnical (in green) and the decisional (in purple) dimensions of autonomy and distinguishes the three components that are useful to analyse the overall autonomy of farming systems: embeddedness, dependency, and footprint

- the **forms of embeddedness** of farms, groups of farmers, or agricultural supply chains within territories, that enable to understand how these entities support themselves by using local resources (both natural and socio-economic resources) and valorise these resources. The embeddedness of agricultural activity within a territory thus constitutes a means to increase the autonomy of LFSs.
- the **forms of dependency** of farms, groups of farmers, or territories with respect to inputs, technologies, and the actors that provide them. Increasing the autonomy of LFSs in terms of inputs and technologies calls into question and reconfigures their dependency on socio-economic actors.
- the **forms of the footprint** of farms, groups of farmers, or agricultural supply chains on territories, in terms of their social, economic, and environmental impact. Increasing the autonomy of LFSs has to be assessed in view of their sustainability.

Three approaches grounded on different disciplines were reviewed to analyse the forms of embeddedness, dependency, and footprint, and consequently the autonomy of farming systems and territories. We present these three approaches, their advantages and limitations, and the opportunity to hybridise them in order to get an integrated view of LFSs' autonomy.

Closing Cycles: A Material Flows-Based Approach

Autonomy can be understood as the flows of material existing between components within a farming system and between farming systems and other environmental and socio-economic components of territories and supply chains. Upstream of production, natural resources are used to produce the inputs (e.g. energy) necessary for systems to function. Downstream, beyond the sale of agricultural products, the “storage” compartments of the biophysical environment (the biosphere, the atmosphere, oceans) absorb, accumulate, and sometimes recycle the elements rejected by production systems. In these studies, the solution to improve the autonomy of farming systems and to reduce their negative impact on the environment is to promote intra- or inter-system internal recycling and thus to reduce the use of resources upstream and waste downstream of the production process.

The analysis of territorial metabolism (Bonaudo et al. 2016) has given a toolset to describe which products or by-products of an activity, considered its wastes, could be valorised as resources for another activity. Likewise, life cycle assessment (LCA)-based eco-design or assessment approaches follow the same logic, which aims at considering a “material” form of autonomy by organising optimal recycling of flows of materials. On the territorial level, this ideal state can be achieved by combining systems into a complex organisation, which is not, however, taken into consideration when the only thing measured is flows, in other words, that which is consumed, produced, reused, transformed, and ultimately rejected. In this case, the system is thus considered a “black box”.

Flows between crop and livestock farming components in LFSs at the farm or the territory levels can be analysed from this point of view: crops provide the energy, protein, minerals, and vitamins to animals, which in return provide fertilisers that are beneficial for plant growth through their excrement. Several authors have used this approach to show that beyond the “apparent” autonomy in the complementarities between LFS subsystems, the whole can remain heavily dependent on exogenous resources. For example, Nesme et al. (2016) show that in the exchange of materials between organic cereal farms and livestock farms, the production of crops used as animal feed is also heavily dependent on manure fertilisation from conventional livestock farms, as such importations are allowed in organic crop farming. However, these manures themselves come from conventional livestock farms that may use feed from conventional cereal farms. Likewise, Regan et al. (2017) demonstrate that increasing the exchanges between cereal and livestock farms to close the biogeochemical cycles can sometimes lead to increasing the local fodder supply of livestock farms. To balance animal rations (energy and protein), livestock farmers had to buy protein concentrates, and so increase their dependence on nitrogen inputs. Last of all, depending on the geographical level considered, the energy costs of transporting materials can be very high (Asai et al. 2018) and can call into question the relevance of exchanges in economic and environmental terms.

The material flows-based approach focuses on the biotechnical dimension of the autonomy of farming systems, and more particularly on their footprint. It is often

limited in terms of dealing with topics related to the embeddedness of production systems, because it only allows to establish an assessment of flows, which has led many authors to broaden their perspective, in particular in the direction of territorial ecology (Buclet 2015; cf. § 2.3).

Managing Agroecosystems: A Functional Approach

The autonomy of LFSs can also be analysed by looking at the technical management of the biological resources of agroecosystems on different levels of space and time, and the performances resulting from this management. It is therefore necessary to study the structure and functioning of agroecosystems and to identify levers for action that increase “biotechnical” autonomy (Fig. 1). The valorisation of local plant resources and organic fertilisers (embeddedness) in LFSs reduces the use of feed inputs, synthetic fertilisers, and fossil energy exogenous to the system (dependency). The assessment of the impact of such practices on the LFSs in terms of sustainability and resilience (footprint) is required.

As for the flows-based approach (cf. § 2.1), the functional approach based on LFSs’ autonomy focuses on farming practices that increase the local embeddedness of animal and plant productions by matching them (Hendrickson et al. 2008; Lemaire et al. 2014). However, the latter aims at integrating plants and animals to offer a balanced ratio of energy and protein to animals, and in return, for crops (e.g. legumes) or livestock manures to allow soil fertility to be maintained rather than reducing material losses as a whole. In particular, ruminant LFSs that are self-sufficient in inputs are mainly systems that combine several crops with livestock farming, and in which grass makes up a significant part (Grolleau et al. 2014; Coquil et al. 2014). Grass has multiple advantages: it has a good balance between energy and protein for ruminants, provides permanent ground coverage, and is an inexpensive resource. Legumes also have advantages owing to their symbiotic fixation of atmospheric nitrogen and the provision of high-protein animal feed. Last of all, the insertion of by-products into monogastric animal rations or dairy cattle farming, as well as inter-cropped meslins, also promote a reconnection between animals-plants-soil, all the while allowing for waste recycling, to limit the footprint (Dumont et al. 2017).

The levers for action based on the functional management of agrobiodiversity are concretised in the form of the animal or plant component of the agroecosystem, with the goal being to maintain consistency between these components in view of promoting embeddedness and limiting dependency of LFSs. In mixed crop-livestock farming systems, diversification of the cropping plan and the extension of rotations provide feed that is more balanced in terms of energy and protein for animals (Russelle et al. 2007), and therefore limits the use of external feed inputs. It also

promotes synergy between species or functional types of fodder and/or farmed plants (e.g. the combination of grasses and legumes) in time and space. Thus, it induces a better management of plant health by minimising the use of phytosanitary products (Martin et al. 2016), and ensures soil fertility by minimising the use of mineral fertilisers (Lemaire et al. 2014). To improve LFSs' autonomy, levers also concern the diversification of animals themselves (Magne et al. 2017). This consists in: (i) choosing genotypes best suited to local soil-climate conditions and, in particular, local fodder resources, such as local breeds (Lauvie et al. 2011), crossbred animals (Lopez-Villalobos et al. 2000), and/or breeds with a good feed conversion efficiency (Delaby et al. 2009); (ii) combining animals to take advantage of the complementarity of their features, such as combining breeds in dairy herds to produce milk with low feed inputs (Magne et al. 2016), or cattle and small ruminants during grazing to make the best use of fodder resources and to achieve better overall animal productivity and parasite management (Dumont et al. 2013); and (iii) using the diversity of the physiological stages of animals within the herd to match animal needs with the fodder offering, and to deal with the risks of limited fodder resources during certain periods of the year (Blanc et al. 2006).

Some studies carried out on the assessment of autonomous LFSs (systems with little dependency on inputs) showed that these systems were a win-win situation for all three dimensions of sustainability (the economic, environmental, and social dimensions). From the economic point of view, they prioritise high added value per hectare by decreasing input consumption (and therefore dependency) and by mobilising ecosystem services (Garambois and Devienne 2012). They are less dependent on market fluctuations (Benoit and Laignel 2009). From an environmental point of view, they have a smaller footprint in terms of nitrogen, pesticides, and wild biodiversity (Le Rohellec et al. 2009). Last of all, from the social point of view, they allow for more decisional autonomy (Coquil et al. 2014).

The literature reports on multiple limits to this functional approach to LFSs' autonomy. First, few studies address the input autonomy of farming systems while integrating all components of the system. Specifically, the study of LFSs and crop systems has long been carried out separately by livestock production researchers and agronomists, respectively. Studying mixed crop-livestock farming systems requires animal production to be associated again with plant production. It is therefore necessary to analyse the complementarities and the flows between these productions, as well as the recycling of by-products, alternative crops, and intercrops for animal feed. In addition, few studies combine an analysis of farmers' practices with an analysis of the forms of organisation of the socio-economic and sociotechnical actors involved in the management of autonomous LFSs. This functional approach to LFSs' autonomy is therefore focused on its biotechnical dimension, and is useful for studying the embeddedness, dependency, and footprint of LFSs. However, it is not particularly relevant for studying the decisional dimension of autonomy and its variants in terms of these three components.

Coordinating Actors: An Approach Based on Organisation and Values

The LFSs' autonomy can also be examined by looking at the actors' forms of organisation and the values that they share within farms, groups of farmers, or agricultural supply chains in territories. These forms of organisation can either impede or promote LFSs' autonomy, as they determine the nature and the extent of the coordination between actors and material, economic, and potentially labour flows at the different levels of action (within farms, farm networks, agricultural supply chain, etc.). Sharing values helps farmers build the necessary bond for effective cooperation to develop farming systems' self-sufficiency in terms of inputs (Asai et al. 2018). For that, these farmers draw support from self-organised networks of actors and the experience-based knowledge that they acquire along the way (Coquil et al. 2014). In this sense, they are autonomous in establishing their own technical guidelines and resource portfolios, partially independent of the dominant sociotechnical regime (Rosset and Martínez-Torres 2012; cf. chapter "The Key Role of Actors in the Agroecological Transition of Farmers: A Case-Study in the Tarn-Aveyron Basin"). The issues and determinants of LFSs' autonomy can therefore be addressed as comprehensive research or intervention-research problems focusing on a system of socio-ecological interactions (McGinnis and Ostrom 2014). Comprehensive research seeks to understand how flows of materials and the social, political, and economic organisation of human societies are structured. Intervention-research seeks to participate in designing a collective organisation aimed at achieving a territorialised system of actors, such as a group of crop and livestock farmers to collectively integrate crop and livestock production.

On the territorial level, comprehensive research analyses a variety of actors and issues – whether industrial, urban, or agricultural – from a multidisciplinary viewpoint. Territorial ecology (Barles 2011; Buclet 2015) is an example of an approach offering a combined analysis of territorial resources, systems of activities, and the forms of governance of these resources and activities. It encourages the adoption of a perspective on the interactions between farms, groups of farmers, agricultural supply chains, and territories that takes the organisational and identity dimensions into account. It requires the interplay between actors (capacity for action, negotiation, etc.), the values of these actors, and their impact on forms of territorial embeddedness to be described by identifying what resources and activities they will prioritise. This ranking of priorities is based on their power of action and their vision of the system's autonomy. Different focuses can be adopted, depending on the goals pursued: a business strategy, the values of actors, the qualification of resources, or the relation to consumption. Analysing business strategies (Saives 2002; Hannachi et al. 2010) allows one to distinguish between two types of spatial behaviours of companies: localisation behaviours and territorialisation behaviours. The analysis of values and in particular the vision of autonomy enables one to understand farmers' relations (or the absence thereof) with their ecological, economic, and social environment (Stock and Forney 2014). Autonomy as a value

determines actors' strategies to better valorise the resources available in their territory (embeddedness). These strategies can be manifest in the search for and the sharing of knowledge and technologies through local networks of farmers and advisors. They can also aim at bringing together a broader diversity of actors, in particular around the development of local food systems (Bellows and Hamm 2001). The analysis of the valorisation of agricultural products, and in particular the territorial qualification processes for food products (Ilbery et al. 2005), affords insight into the process of constructing territorial resources jointly between farmers or within supply chains and territories. This clarification could benefit from an analysis of the relations between production and consumption within supply chains, specifically in terms of the socio-spatial proximity between the producers and consumers of a territorial resource (Deverre and Lamine 2010).

In a territory, intervention research, such as that carried out during the TATA-BOX project, aims at supporting the design of a collective organisation oriented towards a territorialised system of actors, on the basis of a transdisciplinary viewpoint. It can draw support from the result of comprehensive research in order to understand the interactions between farms, groups of farmers, agricultural supply chains, and territories from the organisational and identity perspectives. It subsequently requires the organisation of a debate around the notions of autonomy and the motives behind collective organisation (Ryschawy et al. 2017). This phase should establish common values between actors who wish to engage in the collective organisation, or alternatively, allow them to exit the process. The following stage consists in applying tools to design and assess scenarios that enable the actors involved to analyse the advantages and limits of diverse forms of collective organisation, choosing one to ultimately implement (Moraine et al. 2016). The scenario assessment phase can partially use a flows-based and/or functional approach (via the associated practices and performances), in particular to balance the material, economic, or labour flows between actors (Barnaud and Van Paassen 2013). It is necessary to ensure that the scenario retained does not contribute to increasing power disparities between actors. The assessment must also consider actors' degree of satisfaction with respect to their decisional autonomy (Ryschawy et al. 2017).

The organisation and values approach to LFSs' autonomy thus proves to be appropriate for addressing its decisional dimension of autonomy, based on the components of embeddedness, dependency, and footprint. However, it is not suited to addressing its biotechnical dimension and its variants in terms of these three components.

An Integrated Approach to Autonomy

This brief literature review shows that the three approaches implemented to analyse the autonomy of LFSs put emphasis on either one or two of its components (i.e. embeddedness and/or dependency and/or footprint), as well as integrating one or both of its dimensions (i.e. biotechnical and/or decisional autonomy (Table 1).

Table 1 Contributions of the three research approaches to analysing the autonomy of LFSs. The “X”s indicate the dimensions and components of autonomy to which each approach contributes. The coloured rectangles indicate the dimensions, approaches, and components addressed in each of the case studies (presented in section “[Case study 1: a methodology to analyse the overall autonomy of dairy sheep farms in Aveyron](#)”): case study 1 is in green; case study 2 is in orange. The continuous/dotted lines refer to the spatial level taken into account in each case study: the farm level is indicated with a continuous line; the territorial level with a dotted line

		DIMENSIONS					
		Biotechnical			Decisional		
COMPONENTS		Embeddedness	Dependency	Footprint	Embeddedness	Dependency	Footprint
APPROACHES	Flows-based		X	X			
	Functional	X	X	X			
	Organisation and values				X	X	X

Our analysis framework (Fig. 1) structures and hybridises these three components and these two dimensions of the autonomy of LFSs. To illustrate this integrated approach, we apply this analysis framework *a posteriori* to two case studies carried out as a part of the ANR TATA-BOX project. The goal is to show how these two case studies address the different dimensions and components of the analysis framework that we are developing here, and the limits of these studies with respect to the framework. The first case study aims at producing a methodology to analyse the global autonomy of dairy sheep farming systems in the Roquefort region (Thenard et al. 2014, 2016). The level of analysis is that of the farm. The second case study explores the design of LFSs’ autonomy through integrating crop and livestock farms on the level of a small territory in the Occitanie region (Ryschawy et al. 2017).

Case Study 1: A Methodology to Analyse the Overall Autonomy of Dairy Sheep Farms in Aveyron

This study used a functional approach and focused on the biotechnical dimension of LFSs’ autonomy (Table 1). It consisted in analysing farmers’ management and assessing the multiple performances of the LFSs of a group of dairy sheep farms in south-western France (territory of the Roquefort PDO), that were seeking to become more autonomous through better use of the territory’s fodder resources. To do so, we developed a three-step methodology: (i) collectively defining what autonomy encompasses in these LFSs; (ii) describing and characterising LFSs, based on the combinations of levers of action implemented by livestock farmers to increase their

autonomy; and (iii) assessing the multiple performances, including autonomy, of LFSs. The methodology implemented enabled us to address the decisional dimension of these farms' autonomy without, however, studying it.

Step 1. Participatory Workshops to Comprehensively Describe Autonomy in Sheep Farming Systems

This first step was carried out as a participatory workshop with sheep farmers and some of their advisers. It aimed at building a common framework for LFSs' autonomy. The workshop consisted of an individual "post-it" session, followed by the drawing of a collective cognitive map to establish common ground (Fig. 2). The map showed that LFSs' autonomy related to three main categories of goals for the farmers and their advisers. The first goal was to valorise local resources to feed sheep, and in particular the fodder and pastoral resources of the Roquefort territory (in green, Fig. 2), which expressed the embeddedness of production systems in the "terroir" (term used by the farmers). The second goal was to reduce input

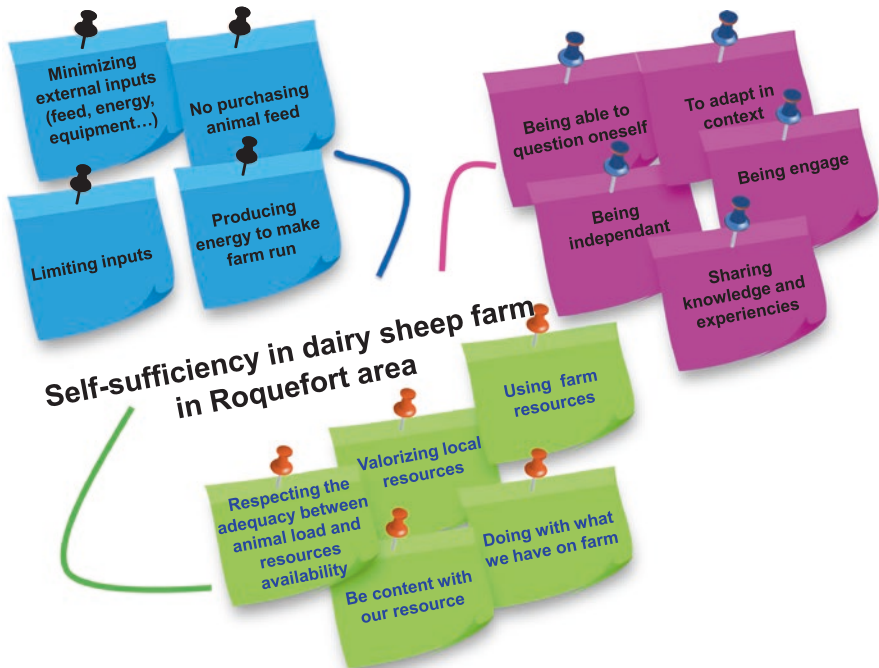


Fig. 2 Cognitive map built in collaboration with the group of sheep farmers and their advisers to define the meaning of autonomy for them in Roquefort territory: valorising local resources (in green); limiting the use of inputs and purchases (in blue); and the ability to make their own decisions (in pink)

use – whether feed inputs for animals, agrochemical inputs for crops, or equipment inputs for livestock or crop management (in blue, Fig. 2) – and thus for farmers to remove themselves from a situation of dependency on suppliers. The last goal was for farmers to be able to make their own decisions, to adapt to the soil-climate and economic contexts, and to share their experiences within peer groups (in pink, Fig. 2). It thus represented the decisional dimension of autonomy.

Step 2. Characterisation of the Operation of Dairy Sheep Farming Systems from the Angle of Biotechnical Autonomy

The second step was based on analysing the data collected from the 27 dairy sheep farmers in the Roquefort area, expertly selected based on the criteria of “seeking autonomy of sheep farming systems”. This step was based on an approach focusing on the flock and fodder practices managed by farmers to increase the embeddedness and reduce the dependency of sheep farms. Ten kinds of practices categorised were identified as levers for action implemented by farmers to increase their “biotechnical” autonomy. They were organised into three types of levers for action: (1) managing the diversity of animal and plant resources; (2) managing the renewal of animal and plant resources; (3) managing input needs (Table 2).

Analysing combinations of practices has allowed researchers to characterise the diversity of LFSs’ management of biotechnical autonomy along three major guidelines (Thénard et al. 2014). The first guideline presents the way that farmers manage the duration of the sheep lactation period, and the need to make use of exogenous dietary supplements to feed them throughout the period. It contrasts farms where sheep are milked for a short period while being fed rations based on on-farm fodders, with farms where sheep are milked for a longer period and fed with purchased concentrates in addition to the on-farm fodders. The second

Table 2 Ten practices organised into three levers for action implemented by the 27 interviewed sheep farmers to increase the autonomy of their farm

	Three levers for action used by the interviewed sheep farmers		
	Managing the diversity of animal and plant resources	Managing the renewal of animal and plant resources	Managing the reduction in input needs
Livestock and fodder management practices	Criteria for selecting lambs	Herd management (reproduction and dry-off)	Suitability of the milking period with grass growing
	Diversity of pastures grazed in the spring	Ways of using the animal genetic progress	Origin of concentrates for sheep feed
	Fodder resources used in summer	Diversity of the fodder and/or pastoral resources of the farm	Outdoor or indoor management of lambs Supplementary feeding of sheep in summer

guideline describes the way that farmers manage the diversity of fodder resources and sheep reproduction. It thus contrasts farms based on diversified fodder systems and natural animal reproduction, with farms based on more intensive fodder systems with limited diversity and artificial reproduction. Last of all, the third guideline presents the types of females desired and selected at the farm. It contrasts farmers who use “milk yield” as the only criterion for selecting females and raising lambs in a sheep pen, with farmers who use selection criteria other than milk yield and raise lambs outside for some months of the year.

Four types of livestock farms are therefore distinguished based on their strategy to increase their autonomy.

Type 1: Producing the Milk Permitted by the Territory's Resources These farms adapt the duration of the sheep-milk production period to the on-farm forage and pastoral resources. The milking period overlaps with the grazing period, including during the summer, thanks to the use of pastoral resources. These farmers try to combine significant embeddedness with low dependency on feed inputs, even if it means producing less than the average in the region. Biotechnical autonomy is also closely tied to a desire for decisional autonomy and to the values promoted by these sheep farmers.

Type 2: Producing Milk by Optimising Fodder Stocks to Provide for Significant Sheep Needs These farms are based on the use of “intensified” and low-diversified seeded grasslands with grasses or grass/alfalfa mixtures. These grasslands are used to produce fodder stocks and are also grazed during the spring. The farms are autonomous in terms of energy supply of animals but not protein supply. Farmers therefore use nitrogen concentrates to provide for the significant nutritional needs of their sheep, which are selected based on their milk yield. They also use mineral fertilisers to ensure the production of the fodder necessary for milk production, which is mainly carried out in a sheep barn during the winter and for a short time in the spring. Therefore, feed self-sufficiency indicates a strong desire for embeddedness in the *terroir*, but follows an efficiency approach that results in high nitrogen dependency of farms.

Type 3: Producing Milk through Organic Farming These farms use a wide variety of forage resources, including pastoral resources, native grasslands and highly diversified seeded grasslands. They do not use agrochemical fertilisers, which are prohibited in organic farming. On these farms, milk production is managed in accordance with the grass-growing season, beginning in the spring and often lasting until the autumn. Taking into account the lower quality of fodder resources, in particular due to the fact that they do not receive mineral fertilisers, sheep farmers use nitrogen and energy concentrates to provide sheep rations. Autonomy is based on a low level of dependency on synthetic inputs. Yet the high degree of embeddedness of these sheep farms in the local resources of the *terroir* leads to their dependency on animal feed inputs. Reducing their environmental footprint is one of the ultimate goals of this type of sheep farm.

Type 4: Producing Milk by Diversifying the Fodder System and by Integrating Crop and Livestock Farming These farms are based on a wide diversity of cultivated plant resources which enable them to establish stocks and ensure grazing by alternating types of seeded grasslands – or crops – over the year, including summer crops (e.g. intercropping, sorghum, etc.). Using a wide diversity of crops allows farmers to limit purchases not only of feed concentrates but also of agrochemical fertilisers because legumes and intercropped cover crops are used extensively, and conservation agriculture practices are sometimes implemented. This diversified fodder and crop system enables sustainable milk production both in the sheep barn and during the grazing period, including in the summer. The autonomy of these sheep farms is thus based on a significant embeddedness in the local soil-climate context, along with a low dependency on inputs.

Step 3. Assessing the Performance Profiles of the Different Types of Sheep Farms

This third step aimed at assessing the technical-economic and environmental footprint of the four types of sheep farm. The technical-economic performances of sheep farms were therefore assessed based on three categories of performance: herd productivity (ewe milk production, lambing rate and prolificacy), economic efficiency, and the feed self-sufficiency of the herd. For each category, multiple indicators were defined and aggregated (Fig. 3). Environmental performances were assessed during a second series of interviews with farmers, based on their agronomic practices. These were categorised into different criteria, depending on whether they related to practices to conserve soil fertility, to limit agrochemical inputs, or to manage plant diversity.

The analysis of technical-economic performances shows that the four types of sheep farm present different trade-offs between herd productivity, economic efficiency, and feed self-sufficiency (Fig. 3). It appears that type 4 farms present the most balanced profile. Type 2 farms have the least feed self-sufficiency, the highest herd productivity and the lowest economic efficiency. This proves that increasing animal production does not systematically entail best economic performances. Compared to type 4 farms, type 1 farms have the same level of feed self-sufficiency, slightly lower economic efficiency and significantly lower herd productivity. One of the main reasons is that these farmers seek to minimise all kinds of purchases and use local natural resources without seeking to better use the agronomic potentialities of the environment to diversify the fodder system. Last of all, type 3 farms have the least balanced performance profiles. They have the same herd productivity as type 1 farms, with a slightly lower economic efficiency, but they have the lowest feed self-sufficiency of the four types of farm identified. The added value of organic milk production therefore allows them to have an economic efficiency that is not too strongly impacted by the low feed self-sufficiency of the herd.

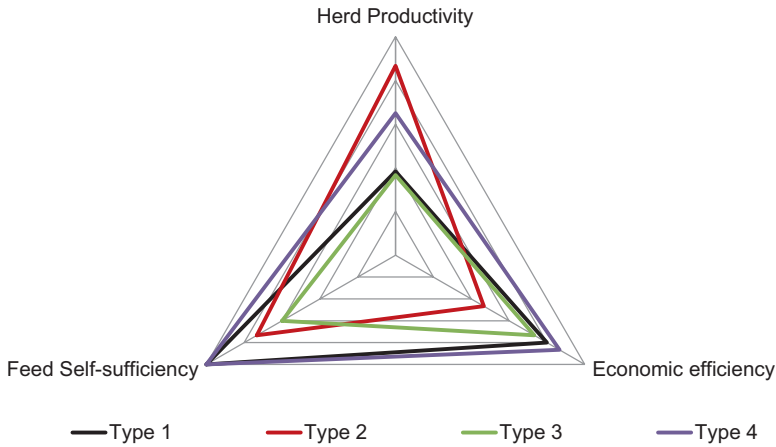


Fig. 3 Technical-economic performance profiles of the four types of sheep farm characterised above

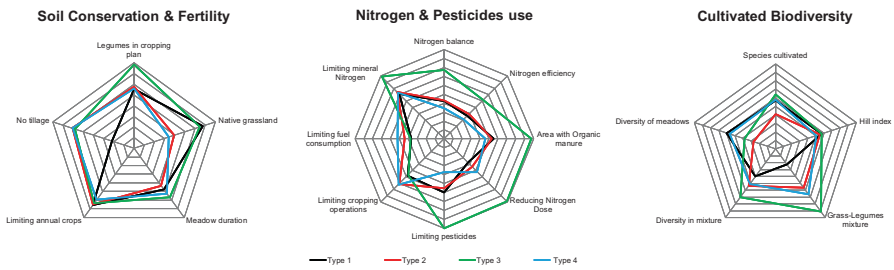


Fig. 4 Assessment of the environmental performances of the four types sheep farming system characterised

The assessment of sheep farms’ environmental performance (Fig. 4) showed that type 4 farms had the best scores for the preservation of soil fertility. These farms practice no-tilling and simplified cropping techniques. Inversely, type 1 farms have poorer performance around the maintenance of soil fertility, due to the use of tilling. As for type 3 farms, their performance is good, owing to the extensive use of legumes (sainfoin, alfalfa, clover, etc.). With respect to the “use of chemical inputs”, type 3 farms present the best performance in terms of indicators related to: (i) the risks of pesticide use, because it is the only type that does not use pesticides; and (ii) the nitrogen use due to planting legumes and not purchasing mineral fertilisers. The other three types farm have equivalent performances. Last of all, with respect to the “valorisation of crop diversity”, the strengths of type 3 concern the management of species diversity, in particular legumes, whereas for types 1 and 4, their advantages are around managing types of grasslands.

The analysis of sheep farming systems shows that the forms of autonomy sought by sheep farmers differ. The components of the analysis framework that we offer allow us to observe these forms. For example, type 1 is built around autonomy based on the valorisation of local resources as well as independence from upstream and downstream structures. Sheep farmers seek to reduce herd feed inputs even if it means reducing the volume of milk produced, depending on the farm's agronomic potential to produce fodder, crops and legumes. In this way, they reduce the farm's environmental footprint. Type 2 farms seek to increase their flocks' forage and feed self-sufficiency, without actually attaining it in terms of either dietary nitrogen supplementation or agrochemical inputs, because of the significant pressure on the selected sheep to produce large quantities of milk. One of the levers mobilised by these farmers is to intensify grasslands and crops, which requires the use of mineral fertilisers and pesticides. They seek production efficiency over valorising local natural resources and being independent of upstream/downstream structures. On the other hand, they limit tilling to reduce the workload or soil erosion. Yet they cannot go without pesticides (glyphosate in particular), which causes the farm to have a larger environmental footprint. Type 3 farmers, who have organic farming management, naturally seek to reduce their farms' environmental footprint by not using agrochemical inputs and by valorising the natural resources of the territory. They are however forced to purchase feed supplementation to meet their flocks' requirements, as fodder produced without mineral fertilisation has low yields and nitrogen contents. Last of all, type 4 livestock farmers act to diversify the fodder system and balance the offering with their animals' needs. They limit soil tilling by combining legume crops with long and diversified rotations, drawing inspiration from conservation agriculture. By doing so, they reduce synthetic inputs and valorise the resources and potentialities of the region. They decrease their dependency on structures upstream from the farm, along with their environmental footprint, all the while maintaining the best profile in terms of productivity/economic efficiency and feed self-sufficiency.

Case Study 2: Co-Design of Scenarios of Exchanges Between Crop and Livestock Farmers to Improve Autonomy on the Level of a Small Territory

Coordination Between Farmers to Strengthen Autonomy on the Collective Level

This case study presents an attempt to integrate crop and livestock farming in territories in collaboration with a group of crop and livestock farmers. The implementation of this coordination between farmers has a twofold impact: on each farm, and collectively. Various approaches were therefore used to address autonomy, according to the organisational level considered and in view of the components and priority dimensions (Table 1).

Scenarios of exchanges between crop and livestock farmers were jointly designed in collaboration with organic farmers in Tarn-et-Garonne wishing to increase their embeddedness and decrease their dependency on feed inputs and fertilisers. In this group, livestock farmers wished to develop a local supply of concentrates, whereas crop farmers wished to diversify their cropping plans by inserting legumes into them, and to collect manure to enrich their soils. A functional analysis was carried out from the biotechnical perspective to estimate the demand and offering of concentrates and manure, i.e., the dependency, and the potential to increase the embeddedness of each crop or livestock farm. Subsequently, an analysis of biotechnical flows allowed for a comparison of the overall supply and demand on the collective level, in order to estimate the dependency of the group. This first analysis involved 24 livestock and crop farmers belonging to the Bio82 collective and their facilitator (Fig. 5).

Several scenarios of crop-livestock integration were designed, depending on the form of organisation of biotechnical exchanges between farms. The scenario chosen by the livestock farmers was based on the insertion of grasslands (mainly alfalfa) and cereal-legume mixtures into rotations and manure exchanges (Moraine et al. 2016). It increased the embeddedness and limited the dependency of all the farms. In such a scenario, annual exchanges amounted to 341 tonnes of alfalfa, 125 tonnes of a barley/peas-type cereal-legumes mixtures, and 88 tonnes of hay provided by the crop farmers. In return, 1059 tonnes of composted manure were available to restore the soil organic matter exported by crop farms. This scenario was very promising in terms of closing the mineral cycles, managing the agroecosystems, and bringing together actors around common values. However, across an area of 1655 ha, the distances between crop and livestock farmers were very large, and logistic constraints proved to be too complex to manage.

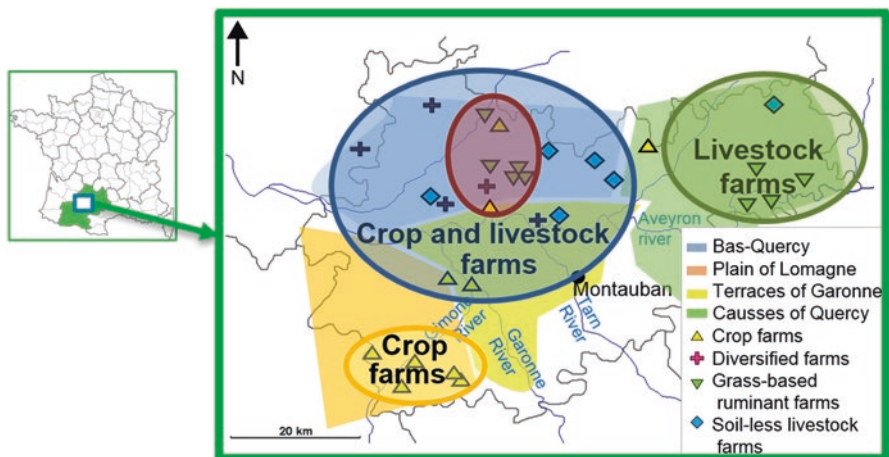


Fig. 5 Location of the crop and livestock farmer groups involved in the process. The 24 farmers initially involved in the research, were located in three contrasting soil-climate areas represented in yellow, green, and blue. The seven farmers selected for the final crop-livestock integration scenario were located in a single soil climate area (in blue) and were delimited by the red circle

As a result, the approach was repeated with seven livestock and crop farmers (Fig. 5), who knew one another very well and were very close geographically (less than 20 km apart). The scenario favouring the maximum synergy was based on exchanges of 40 tonnes of harvested barley-pea cereal-legumes mixture, 18 tonnes of maize for grains, 8 tonnes of alfalfa hay, and 4 tonnes of sunflower for grains provided by the crop farmers. In return, the livestock farmers supplied 105 tonnes of manure. The exchanges within this subgroup were less ambitious in terms of volume, but they enabled the redesign of livestock and crop farming systems to close mineral cycles, with a view to achieving a smaller footprint and to coordinating actors in moving towards more decisional embeddedness. The scenario also appeared to be more feasible in terms of coordination and logistics (transportation, storage, etc.), and it limited the decisional dependency on other actors (transportation or storage companies, etc.). To assess these scenarios, we simultaneously considered footprint and dependency from the biotechnical perspective, by carrying out a functional analysis on the farm level as well as a flows-based analysis on the level of the group of farms. We also assessed embeddedness, dependency, and footprint from the decisional perspective on the level of the group of farms.

Sustainability and Performance of the Crop-Livestock Integration Scenarios

The crop-livestock integration design scenarios allowed farmers to collectively increase autonomy with respect to inputs, and thereby to reduce dependency on exogenous supplies by increasing the territorial embeddedness of farms (Fig. 6). On the collective level, livestock farmers became completely autonomous thanks to local exchanges with crop farmers, thus strengthening their biotechnical embeddedness and reducing their dependency. Crop farmers also improved their embeddedness and limited their dependency on organic nitrogen inputs (feather meal, etc.) exogenous to the territory, by introducing legumes into their rotations and through the contribution of organic manure from livestock farms. In addition, the diversification of rotations allegedly limited the risks of disease and the use of irrigation water by limiting the surfaces planted with crops with significant consumption needs, such as maize, thus reducing the environmental footprint of crop farms. The multi-criteria assessment on the collective level showed that spatial and temporal heterogeneity of crops was favoured, and that autonomy (energy, mass, and protein autonomy) was increased in relation to the decrease in use of inputs external to the group, thus also increasing embeddedness and reducing biotechnical dependency. Therefore, as Asai et al. (2018) emphasised, higher economic and environmental costs with respect to fuel use should be estimated for groups of farmers, due to the more frequent individual transportation of crops, fodder, and manure.

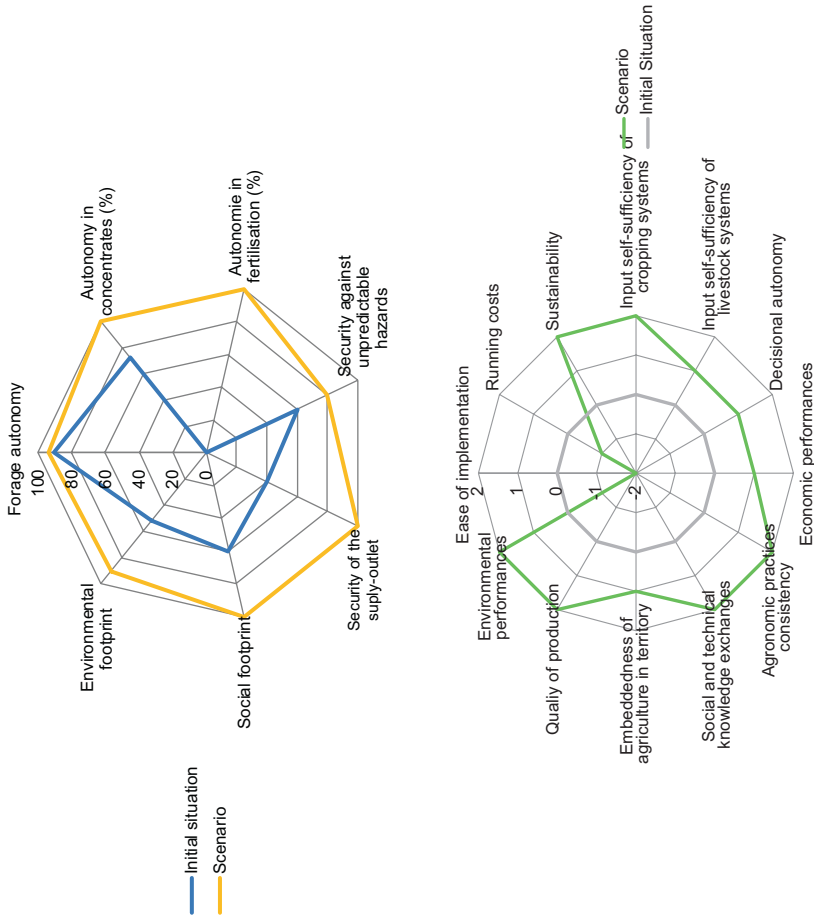


Fig. 6 Radar chart assessing the scenarios of crop-livestock integration designed at the collective level compared to the initial situations (to the left: group of 24 farmers; to the right, group of 7 farmers)

A Participatory Process to Examine the Decisional Dimension of Autonomy

Beyond the purely technical aspect, the exchanges numerically represented through a biotechnical analysis of flows required complex coordination between the actors. We considered this coordination and its impact on embeddedness, dependency, and footprint from the decisional perspective in the context of the participatory design process implemented. In this case, for the first analysis of 24 farmers, we proposed three types of organisation: cooperative-type centralised organisation; multi-relational organisation of the purchase/sale platform type based on ICTs (cf. chapter “[Information and Communication Technology \(ICT\) and the Agroecological Transition](#)”); and an intermediate option called multi-centred organisation, in which multiple, more localised small groups self-organised. Faced with the three organisational scenarios proposed, the farmers clearly declined the centralised option, as it went against their goal of decisional autonomy and their idea of direct exchanges between farmers. This option would result in higher transaction costs and investments in collective materials, which sounds like the current cooperative model they wished to avoid, preferring to develop their embeddedness and limit their dependency at the collective level. Despite being easier to implement in terms of coordinating actors, the multi-relational ICT option did not offer sufficient stability of exchanges over time to permit the redesign of livestock and crop farming systems. Effectively, the purchase-sale of agricultural raw materials and by-products was therefore generally limited to occasional needs (a drought, for example) and did not make it possible for crop farmers to adapt their cropping plans and rotations to match the needs of the livestock farmers of the group. In contrast, the multi-centred option was chosen and further developed within the subgroup of seven farmers. It appeared to offer the best compromise between closing the mineral cycles, redesigning farming systems, and coordinating actors around common values to develop farming systems’ embeddedness, limit their dependency, and reduce their footprint at the collective level. In this specific case, collective autonomy was based more on autonomy as a value – that is, being independent of suppliers – than on decisional and financial autonomy, which can help to understand the compromises made by the farmers within the group.

In the scenario involving the seven farmers, the group was expected to manage exchanges in coordination with one another by making reciprocal commitments. The increase in the decisional autonomy of farmers with respect to input suppliers was replaced by a high degree of dependency on the farmers in the group. Even though all the farmers in the group were able to improve their overall gross margins as well as their environmental footprint in the exchange scenario designed, they had to invest time in coordinating exchanges, and money in storage materials, and consequently had to agree to reduce their individual decisional autonomy to increase it on the level of the group of farmers. Moreover, compromises between the collective level (with a clear improvement in input autonomy as well as decisional autonomy with respect to suppliers) and the individual level had to be made, with trade-offs that were different depending on the farmer. The question of sharing

materials for storage and potentially transportation was addressed and required investments. To address these questions, an Economic and Environmental Interest Group was set up, also enabling skills exchange and institutional acknowledgement of the agroecological process, as well as increased dependency on one another in the case of collective materials purchases.

During the operationalisation of the process, new locks appeared. For the livestock farmers, modifying rations constituted a large risk in the absence of crop farmers' guarantees around the quality of the feed provided. Moreover, the farm-based manufacture of foods implied more work for them than when they purchased finished feed. For the crop farmers, the utility of using legumes to start their rotation or as an intercrop was high, but it did not always offset the risk of not valorising these crops if the livestock farmers did not purchase them. As Asai et al. (2018) mention, the dependency between farmers is thus reinforced, and the sustainability of exchanges is contingent on the monitoring and facilitation of these exchanges, which require agreements and individual and collective learning processes. Monitoring product orders and deliveries and the implementation of contracts appeared essential. In the context of Bio82, the group leader's departure resulted in a lack of follow-up and disagreements between farmers around schedules and crop exchange commitments, endangering the organisation implemented. Therefore, even though the scenarios designed promoted autonomy in terms of quantity, energy, and protein content, and were in line with the decisional autonomy values of farmers in the group, in terms of reducing the dependency on suppliers, the need for the process to be facilitated during its implementation appeared to be a key factor determining the operationalisation of the scenarios considered.

Conclusion

The conceptual framework developed here enables one to comprehensively analyse the biotechnical and decisional dimensions of the autonomy of LFSs. It is based on three main components for analysing relations between LFSs and their territory: embeddedness, dependency, and footprint. This framework, applied to two case studies carried out under the ANR TATA-BOX project, shows that it is initially the biotechnical autonomy of LFSs that is addressed in this research, with the decisional autonomy dimension being taken into account subsequently and to varying degrees. For example, in the first case study, at farm level, the decisional autonomy of LFSs was not studied as such, even though it was taken into account during the first step of the research process aimed at collectively defining what the notion of autonomy encompassed for the farmers. On the other hand, in the second case study, at the territorial level, it was studied as such, because it constituted a compulsory step to design crop-livestock integration at the territorial level. At the farm level, the two case studies focus on the biotechnical dimension. Developing the decisional autonomy of LFSs would be interesting to understand the factors influencing farmers' choices. Switching to the territorial level requires articulating the functional approach of LFSs with flows-based and organisational approaches, as demonstrated

by case study 2. The tools, methods, and concepts for studying this decisional dimension of autonomy are addressed in other chapters in this book, in particular those on the governance and adaptive management of the AET (*cf.* Chaps. 7 and 6 respectively), as well as the analysis of farmers' networks and information systems for the AET (*cf.* Chap. 8). Ultimately, applying the conceptual framework to our case studies clearly illustrates that to support the AET of LFSs, it is important to integrate the three components of analysis constituted by embeddedness, dependency, and footprint into the biotechnical dimension. It furthermore shows that research efforts should be made to better integrate the biotechnical and decisional dimensions of autonomy.

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