System dynamics assessment to strengthen resilience and sustainability of farming systems. A participatory approach.

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Introduction

Farming systems (FS) in Europe are perceived to have a low level of resilience and sustainability (Reidsma et al., 2020), which increases the chance of undesired, drastic changes in the face of shocks and ongoing stresses. Sustainability refers to the adequate performance and balance of functions across environmental, economic and social domains. Resilience is the capacity of a FS to deal with challenges. Meuwissen et al. (2019) propose a framework to assess resilience of FS that implies the analysis of the following resilience variables: 1) challenges (shocks and long-term pressures) ; 2) functions, considering the provision of private and public goods; 3) resilience attributes, defined as those characteristics which presence make the system more resilient and 4) resilience capacities (robustness, adaptability and transformability). This framework focuses on the assessment of the impact of the challenges on the FS functions performance, leaving a research gap to address the intra and inter relationships between the other resilience variables relate between them, e.g., how challenges relate between them, how challenges relate with resilience attributes, resilient attributes with functions and viceversa. Thus, the aim of this paper is the analysis of the relationships between the resilience variables in a farming system: challenges, resilience attributes and functions

To this end a participatory workshop with the stakeholders in the sheep extensive farming was conducted in Huesca (Northeast of Spain), a FS that has shown some signs of collapse (Paas et al., 2021b). The aim at the workshop was to assess the perception of the stakeholders on how FS react to deal with challenges by building a causal loop diagram (CLD). CLD has been used to study resilience of FS , in which relationships between variables were addressed (Brzezina et al., 2016; Herrera, 2018).However, research so far has not distinguished between challenges, functions and resilience attributes, which entail a novelty in this study.

Methodology

Construction and analysis of the CLD

System dynamics is a modelling method useful to study the internal mechanism of the system and the circular relationships (feedback loops) that drives the outcome of the system (Richardson, 2011; Sterman, 2000) and explain the system's performance. With system dynamics the effect of external variables on the system's performance also might be analyzed. The system dynamics modelling in this study was addressed in a qualitative way, whose aim is to represent the dynamic interactions between variables through a CLD (Walters et al., 2016). Qualitative approaches are needed to understand the dynamics of farms (Darnhofer, 2014), especially the social dimension where usually there is a lack of quantitative data. With CLD, it is also possible to see the potential areas/variables of improvement and intervention (Sterman, 2000) and to evaluate ex-ante the impact of different scenarios and technical interventions and policies (Li et al., 2012; Lie et al., 2018; Shane et al., 2017; Varia et al., 2017).

The CLD was built from contributions from a workshop (FoPIA-SURE-Farm 2) based on the SURE-farm resilience framework (Meuwissen et al., 2019). The workshop was conducted on 14 February 2020 with 18 people participating in the workshop, of which seven were farmers (five of the seven farmers belonged to some kind of association). The rest of participants belonged to the agri-food value chain (veterinaries (3), cooperatives (1) and distributors (1)), and public sector (research institutes and Universities (3), and local public administration (4)). All workshop's participants were actors belonging to the area of study.

In the workshop, participants were asked to identify the most important resilience variables of the FS and to establish relationships between the identified variables. Each participant was able to build a CLD with those variables and some others to make it more coherent. In the CLD, two or more variables can constitute close loops that derivate in cause and effects relationships know as feedback loops. Some variables that are external might also intervene, which influence in the system dynamics but are not influenced by the system (Walters et al., 2016). Then in plenary session, participants put together their ideas and a unified CLD was constructed, which was used as a reference to construct a more complete CLD. This CLD was completed and adapted by the research team with the analysis of the information collected from stakeholders' narratives (comments) related to FS functioning and challenges, but also with information from statistics and scientific literature.

The CLD allowed conducting two different analysis:

- The direction of the intra-inter relationships between challenges, functions and resilience attributes, identifying the cause and effect.

Once the definitive CLD is built, different kind of relationships between different types of resilience variables were identified. The relationships link challenges with functions but also with resilience attributes and other challenges. But relationships might also come up between functions and resilience attributes. Moreover, all these relationships can be in both direction. Throughout the CLD, we were able to determine if the relationships between resilience variables are direct or indirect (a variable is influenced by other variables through a third one (or more)). The analysis of the different feedback loops helped us to study the indirect relationships. Thus, the effect of one variable in other can be determined by the number of intermediate variables and its nature (e.g., if they are or not stocks).

- Analysis of sustainability through the relationship between FS dimensions

In the analysis of sustainability, the interrelationships between and within the three dimensions differentiate in the CLD (economic-technical, social and environmental) were analyzed. This analysis allows determining if a dimension's functioning affects negative or positively the performance of other dimension, that is, if it has an impact on the resilience of other dimension's variables. Sustainable systems are those in which provision of public functions does not jeopardize the provision of public functions, and vice versa. In the same way, sustainability might be compromised when provision of functions in a dimension endanger the provision of functions in other dimension. For that purpose, feedback loops were useful to analyze the connections between the different dimensions and determine if the loss of resilience in a specific domain had an impact on the resilience of other domain's variables.

Area of study

The case study is the extensive sheep sector located in the Huesca province, Northeast Spain, in the Aragón region. Agriculture forms an important part of the economy of Huesca, where ovine production and the practice of transhumance (extensive ovine production) count on a long history (Navarro, 1992). While in history the ovine extensive sector was a strong economic motor in this region, it´s importance has declined heavily in the last 20 years (Gobierno de Aragón, 2020, 2016), together with a vast depopulation of the region (Bosque and Navarro, 2002). Nowadays many farmers moved to a more intensified system (García Manteca et al., 2018) or just abandoned the sector.

Results

Resilience variables identification

The CLD (Figure 1) was built from the list of most important variables identified by participants as a reference, and the information extracted from discussion and literature. In the CLD, three different dimensions can be distinguished according to the nature of variables: economic-technical, social and environmental.

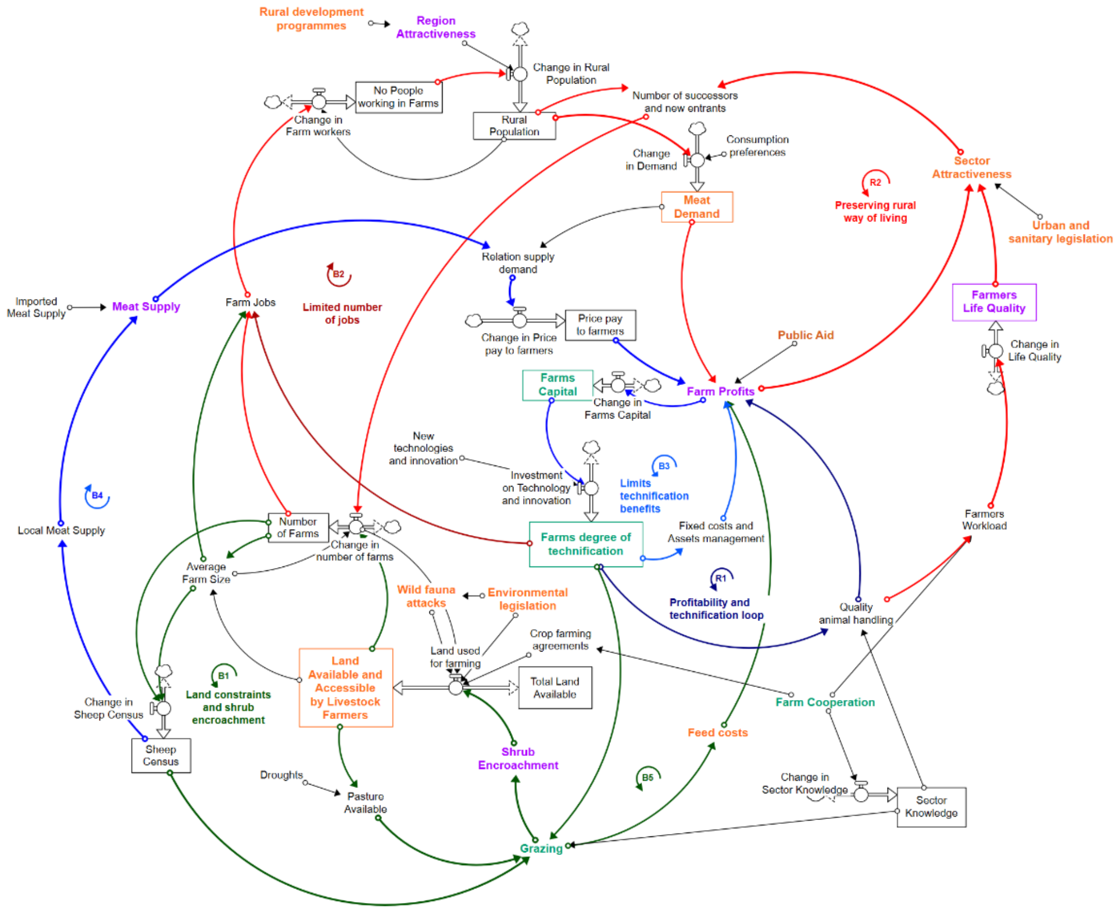

Figure 1: Causal loop diagram (CLD) representing the sheep extensive FS in Huesca.

Table 1 reflect the variables selected by participants, their labelling in the CLD and the dimension in which each variable is located. The identified challenges of the system are present in the three dimensions: the decrease of the meat demand (mostly related to changing consumption preferences), the low attractiveness of the sector (that leads to the low availability of workforce and reduced number of new entrants), the increasing feeding costs mainly related to food inputs, the lack of available and accessible lands for grazing (partially related to wild fauna attacks) and the lack or changes in policies and legislations. Policies were identified in the CLD under four different legislation challenges (the perceived public aids, rural development programs, urban and sanitary legislations and the environmental legislation (access to pasturelands, wildlife protection, etc.)).

Table 1: Description of the most important identified resilience variables in the sheep extensive FS in Huesca (Spain), their correspondence with variables in the CLD and the dimension. Functions and resilience attributes definitions are referred to the ones identified in Meuwissen et al. (2019) and Paas et al. (2021), respectively.

Challenges	*Variable in the CLD*	*Dimension*
Decrease of the meat demand	Meat demand	Economic
Increasing feeding costs	Feed costs	Economic/ Environmental
Lack of available and accessible lands for grazing	Land available and accessible by livestock farmers	Environmental
Low attractiveness of the sector	Sector attractiveness	Social
Changing and insufficient policies	Rural development programmes / Urban and sanitary legislation / Environmental legislation / Public aids	Economic / Environmental / Social
Wild fauna attacks	Wild fauna attacks	Environmental
Functions	*Variable in the CLD*	*Dimension*
Deliver healthy and affordable food products	Meet supply	Economic
Ensure a reasonable livelihood for people involved in farming	Farm profits	Economic
Improve quality of life in farming areas by providing employment and decent working conditions	Farmers quality of life	Social
Ensure that rural areas are attractive places for residence and tourism with a balanced social structure	Region attractiveness	Social
Maintain natural resources in good condition/Protect biodiversity of habitats, genes and species	Shrub encroachment	Environmental
Resilience attributes	*Variable in the CLD*	*Dimension*
Reasonably profitable	Farm capital	Economic
Infrastructure for innovation	Farms degree of technification	Economic
Socially self-organization	Farm cooperation	Social
Coupled with local and natural capital/Ecologically self-regulated	Grazing	Environmental

Functions related to the provision of private goods were considered as the main functions of the FS, namely, ensuring the economic viability of the farm and the provision of affordable and healthy food products (related to the technological-economic dimension), and the improvement of quality of life in farming areas by providing employment and decent working conditions (related to the social dimension). However, other functions related to public goods were identified, either in the environmental or social dimensions, such as the conservation of natural resources throughout the grazing of pasturelands and stubble fields, and the promotion of the attractiveness of the rural areas.

The resilience attributes are also related to all dimensions (Table 1). In the economic-technological dimension, reasonably profitable (identified as farm capital) and infrastructure for innovation (farms degree of technification) were identified. Coupled with local and natural capital /ecologically self-regulated (grazing) and socially self-organized (farm cooperation) were identified for the environmental and social dimensions, respectively.

When analysing the variables all together in the CLD, we observe that most of the system challenges are internal, as they take part of the feedback loops and are impacted by other system's variables. The meat demand and feed costs, which at first it might seem external challenges, they actually are influenced by the rural population (the local breed is consumed in a large extent by local people) and the pasturelands grazing (the greater grazing reduces the external inputs for feedings the animals), respectively. Only the policies and regulations seems to be external challenges, as they have an influence on system's variables but that relationship is not inverse.

We have also observed that some of the identified challenges are actually resilience attributes with a low performance, which can be defined as system weaknesses according to the SWOT analysis. Weaknesses identified for these FS are the policies and legislations and the attractiveness of the sector. These variables can be delimited in some of the resilience attributes defined by Paas et al. (2021). Thus, policies and legislations can be defined in the diverse policies resilience attribute. Regarding the low attractiveness of the sector, it might be addressed by different resilience attributes that are performing low regarding profits and quality of life of farmers. Those resilience attributes are "reasonably profitable", which is also represented in the CLD as farm capital, and "supports rural life" that is the ability to maintain and attract an adequate workforce in the FS.

Relationships between resilience variables

According to the resilience framework proposed by Meuwissen et al. (2019), challenges have a direct impact on functions. For instance, the direct impact of meat demand, public aids and feed costs on farm profits. However, as we hypothesized, this relationship is not the only one detected in the CLD. We have also observed that challenges also impact on system's resilience attributes (e.g., the sanitary and urban legislations contribute to the low attractiveness of the sector), and even on other challenges (e.g., the wild fauna attacks on the availability and access to lands).

The effect of the resilience attributes on functions has also been detected (e.g., the degree of farm technification on farm profits or the grazing on the maintenance of pasturelands by avoiding shrub encroachment). The performance of a resilience attribute might also condition the negative effect of a challenges. For instance, if the level of grazing is appropriate the feed cost are not a problem for farmers; or the cooperation lead to agreements between farmers for the access to lands for grazing. The performance of a resilience attribute can contribute to the performance of another attribute, as the farm capital that condition its degree of technification.

The provision of functions might also condition the impact of challenges. For instance, a high level of shrub encroachment limit the availability of lands. Functions low performance might also lead to a low performance of the system's resilience attributes (e.g., the poor quality of life of farmers in the extensive sector contributes to the low attractiveness of the sector).

The relationships between variables are not only direct, but the impact of one variable on another can be made through the impact on other intermediate variables. A clear example is the function meat supply that does not suffer a direct impact of challenges or the low performance of attributes. This is reflected in the feedback loops. Feedback loops in the economic and environmental dimensions are constituted by a lesser number of variables than in the social dimension. Moreover, those relationships mostly involved resilience variables. In the social dimension, feedback loops are constituted by more intermediate variables, and some of them are stock variables. The greater number of variables and stocks in the social dimension lead to slower effects of some variables on others. This delay effect can be observed in the effect of the low attractiveness of the sector on farm profits.

Analysis of dimensions' relationship and system's sustainability

In the CLD, the three dimensions are linked through different variables. Farm profits is the variable that takes part of the three dimensions feedback loops. Therefore, the poor functioning of the feedback loops in one dimension will affect the functioning of other dimensions' feedback loops throughout the profitability of farms, leading to the unsustainability of the FS. In the social dimension, the low farm profits are reinforced by the negative impact of social challenges, meat demand and sector attractiveness, although the impact of meat demand in farm profits is clearer that the sector attractiveness. In the economic-technified dimension, the technification of farms reinforce positively the farm profits. In the environmental dimensions, farm profits are affected by the feed costs that are directly balanced by the management of the lands (grazing), which is also influence by the farm degree of technification.

In addition to farm profits, other variables also link the different dimensions of the FS. The number of farms in the region is regulated by the environmental dimension through the number of available and accessible lands, and by the social dimension through the number of successors and new entrants, conditioned by the sector's attractiveness. The social dimension is also conditioned by the degree of technification through the quality of life, as it reduces the workforce, and the number of jobs, as technification reduces the need of human workforce. On the other hand, the sheep census conditions the meat supply and the price paid to farms, having an impact in the profitability of the farms. Environmental and social domains are also interrelated, especially through the farmers' cooperation that improves the pasturelands management and reduced the workload.

Conclusions

The CLD based on a participatory approach reveals that challenges affect not only the FS functions but might also turn weaker the FS resilience attributes that in turn affect the provision of FS functions provided. Thus, the strategies for the future need to be diverse enough to deal with challenges but also to deal with weak resilience attributes across the economic, social and environment dimensions. Furthermore, economic, social and environmental dimensions in the FS are interconnected indicating that a combination of actions regarding each dimension need to be performed to turn the system resilient and sustainable. The actions should not only improve farm profits, but the attractiveness of the rural areas and the access to land.

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