Ecological Indicators 132 (2021) 108236

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

# Assessing future sustainability and resilience of farming systems with a participatory method: A case study on extensive sheep farming in Huesca, Spain

Wim Paas [a,b,*], Carolina San Martín [c], Bárbara Soriano [c], Martin K. van Ittersum [a], Miranda P. M. Meuwissen [b], Pytrik Reidsma [a]

[a] Plant Production Systems, Wageningen University & Research, The Netherlands
[b] Business Economics, Wageningen University & Research, The Netherlands
[c] Research Centre for the Management of Agricultural and Environmental Risks (CEIGRAM), Universidad Politécnica de Madrid, Spain

ARTICLE INFO

*Keywords:*
Critical thresholds
Robustness
Adaptability
Resilience attributes

ABSTRACT

Finding pathways to more sustainability and resilience of farming systems requires the avoidance of exceeding critical thresholds and the timely identification of viable alternative system configurations. To serve this purpose, the objective of this paper is to present a participatory, integrated and indicator-based methodology that leads researchers and farming system actors in six steps to a multi-dimensional understanding of sustainability and resilience of farming systems in the future. The methodology includes an assessment of current performance (Step 1), identification of critical thresholds whose exceedance can lead to large and permanent system change (Step 2), impact assessment when critical thresholds are exceeded (Step 3), identification of desired alternative systems and their expected improved performance of sustainability and resilience (Step 4), identification of strategies to realize those alternative systems (Step 5), and an assessment on the compatibility of alternative systems with the developments of exogenous factors as projected in different future scenarios (Step 6). The method is applied in 11 EU farming systems, and the application to extensive sheep production in Huesca, Spain, is presented here, as its problematic situation provides insights for other farming systems. Participants in the participatory workshop indicated that their farming system is very close to a decline or even a collapse. Approaching and exceeding critical thresholds in the social, economic and environmental domain are currently causing a vicious circle that includes low economic returns, low attractiveness of the farming system and abandonment of pasture lands. More sustainable and resilient alternative systems to counteract the current negative system dynamics were proposed by participants: a semi-intensive system primarily aimed at improving production and a high-tech extensive system primarily aimed at providing public goods. Both alternatives place a strong emphasis on the role of technology, but differ in their approach towards grazing, which is reflected in the different strategies that are foreseen to realize those alternatives. Although the high-tech extensive system seems most compatible with a future in which sustainable food production is very important, the semi-intensive system seems a less risky bet as it has on average the best compatibility with multiple future scenarios. Overall, the methodology can be regarded as relatively quick, interactive and interdisciplinary, providing ample information on critical thresholds, current system dynamics and future possibilities. As such, the method enables stakeholders to think and talk about the future of their system, paving the way for improved sustainability and resilience.

## 1. Introduction

Agriculture in the European Union (EU) is generally highly specialized and intensive (Andersen et al., 2007), resulting in an abundant food production, but also often leading to the degradation of natural resources (Tilman et al., 2002). In addition, labor productivity and farm income is low in many farming systems in the EU (DG-AGRI, 2017). From a social point of view, quality of life in rural areas in the EU is often perceived to be low as well, especially in the poorer countries (Eurofound, 2019; Shucksmith et al., 2009). To improve sustainability, a balanced attention

* Corresponding author at: Plant Production Systems, Wageningen University & Research, P.O. Box 430, 6700AK Wageningen, The Netherlands.
*E-mail address:* wim.paas@wur.nl (W. Paas).

https://doi.org/10.1016/j.ecolind.2021.108236
Received 21 December 2020; Received in revised form 10 September 2021; Accepted 23 September 2021
Available online 5 October 2021

for social, environmental and economic system dimensions is important (Kharrazi et al., 2019; Kinzig et al., 2006). Inadequate management of natural resources, for instance, can be seen as a failure to understand how social, economic and environmental dimensions are interrelated (Allison and Hobbs, 2004). Interrelation of these dimensions often results in feedback loops in a system, resulting in non-linear behavior. This makes it challenging to assess and interpret the effect of shocks, stresses and management options on the provision of system functions. In response to this challenge, several resilience frameworks have been developed to study agricultural systems (e.g. Callo-Concha and Ewert, 2014; Meuwissen et al., 2019; Tendall et al., 2015). Sustainability and resilience can be seen as two complementary concepts (Marchese et al., 2018; Meuwissen et al., 2019). Resilience in the form of robustness, adaptability or transformability is needed to maintain or improve sustainability. At the same time, sustainability is needed to ensure the access, availability and quality of resources to buffer shocks and set in motion adaptation or transformation.

For the context of a farming system (FS), Meuwissen et al. (2019) define resilience as the ability to ensure the provision of the system functions in the face of increasingly complex and accumulating shocks and stresses. By emphasizing the importance of system functions, Meuwissen et al. (2019), provide a practical way to combine the concepts of resilience and sustainability in a complementary way. To better understand the potential dynamics of farming systems, current as well as future sustainability and resilience need to be studied. Current resilience of European farming systems was for instance studied by Nera et al. (2020), Meuwissen et al. (2021), Paas et al. (2021), and Reidsma et al. (2020). Towards the future, system behavior may differ according to the development of factors that are exogenous to the farming system (such as population growth and economic development), especially when shocks and stresses increase or when enabling conditions for changes are realized. Trespassing critical thresholds could for instance initiate cascading effects leading to a system decline (Kinzig et al., 2006). To avoid this, institutional actors may deliberately aim at changing threshold levels to enable innovation that provides an alternative to the dominant ways of producing (Westley et al., 2011).

Quantitative models are often used to assess, ex-ante, system performance and behavior. Different types of studies and associated models can be distinguished (Van Ittersum et al., 1998). Based on statistical models, projections or predictions can be made about the average and probable performance for future conditions (e.g. Van Passel et al., 2017). However, because statistical models depend on (data) patterns from the past, only a limited range of all possible futures will be captured. Including a broader range of possible futures (scenarios) increases the opportunity to evaluate farming system resilience under different exogenous conditions that are all possible to happen. Incompatibility of farming systems with certain futures can be seen as a sign of non-resilience in case those systems have no capacity to adapt or transform. In itself, comparing farming systems with a broad range of futures directly contributes to foresight information supporting the capacity to anticipate shocks, which is seen as important for resilience (Mathijs and Wauters, 2020). In so-called explorations, optimization models (e.g. Rabbinge and van Diepen, 2000; Ten Berge et al., 2000; Reidsma et al., 2015) and system dynamics models (Herrera, 2017) can consider multiple possible futures, using scenarios capturing uncertainty on climate change and socio-economic developments. However, these models need parameters which are sometimes also derived from statistical models based on past and current trends. Moreover, optimization models are of limited use for modelling dynamic transformations, as they are generally static.

Participatory methods can take into account multiple scenarios (Delmotte et al., 2013; Walker et al., 2002) and allow for input regarding transformational change (Quist and Vergragt, 2006) and resilience concepts such as critical and interacting thresholds (Resilience Alliance, 2010; Walker et al., 2002). It should be noted, however, that qualitative methods also are influenced by input from statistical sources and experts that extrapolate past trends into the future. We argue that quantitative and qualitative approaches can be complementary. Participatory methods can be quick, interactive and flexible to start discussions about sustainability and resilience in the future, thus laying a base for further discussions and quantitative model-based analyses (Paas et al. 2021). Participatory methods allow for taking into account the voice of individual stakeholders as well as support stakeholder discussions to arrive at a common understanding and a shared vision for improvement of the system or problem under study. Stakeholder participation is important as stakeholders are usually involved in follow-up processes and thus need to agree with the problem definition and proposed action plan (Quist and Vergragt, 2006). Participatory input is valuable because system actors are able to provide empirical knowledge about their system (Delmotte et al., 2013) that reduce knowledge gaps of researchers (Sieber et al., 2018; Vaidya and Mayer, 2014). Vice versa, participatory methods are also important to identify the boundaries of local knowledge (Mosse, 1994). Stakeholder's perceptions are particularly precious, as they can explain or drive system dynamics as stakeholders are important components of socio-ecological systems (Walker et al., 2002). Hence, participatory methods can provide a first exploration of farming system structure, mechanisms, performance and behavior in possible futures.

Discussions with stakeholders about future change can be challenging because stakeholder's mental models usually focus on maintaining the status quo with little imagination of alternative futures (Meuwissen et al., 2020). Other limitations for discussing farming system transformations may relate to the focus of experts on improving efficiency, vested interests, co-dependencies among system actors and institutional path dependence (Meuwissen et al., 2020). Participatory methods should therefore provide opportunities to go beyond the usual extent of stakeholder's mental models. Alternative systems, that avoid critical thresholds and increase sustainability and resilience simultaneously, should be explored, and new strategies to realize those alternative systems identified. To ensure the soundness of intended pathways towards the future, alternative systems need to be compatible with possible future developments of exogenous factors as projected in different future scenarios. High compatibility of desired alternative systems with future scenarios increases the likelihood that those more sustainable and resilient systems will be realized. Consequently, this also decreases the likelihood that critical thresholds will be exceeded, resulting in farming systems with even lower sustainability and resilience levels.

We argue that a quick and flexible assessment of future resilience and sustainability of farming systems is still lacking in literature. In response to this research gap, this paper presents a participatory, integrated and indicator-based method to improve understanding of farming system sustainability and resilience. The method uses the concepts of critical and interacting thresholds to challenge stakeholders in a workshop setting to think about potential non-linear and undesired behavior of their farming system. Following, stakeholders are elicited on desired alternative systems that avoid critical thresholds and thus improve sustainability and resilience (and vice versa). The method is flexible regarding: a. the information sources used as input for the workshop, b. the possibility to include case specific indicators and c. the stakeholder input during the workshop, i.e. alternation of individual input, small group discussions and plenary discussions. We illustrate the usefulness of the approach with an application to the extensive sheep farming system in Huesca, Spain. In this farming system, ongoing, interrelated economic, social as well as environmental developments are increasingly reducing the system's sustainability and resilience.

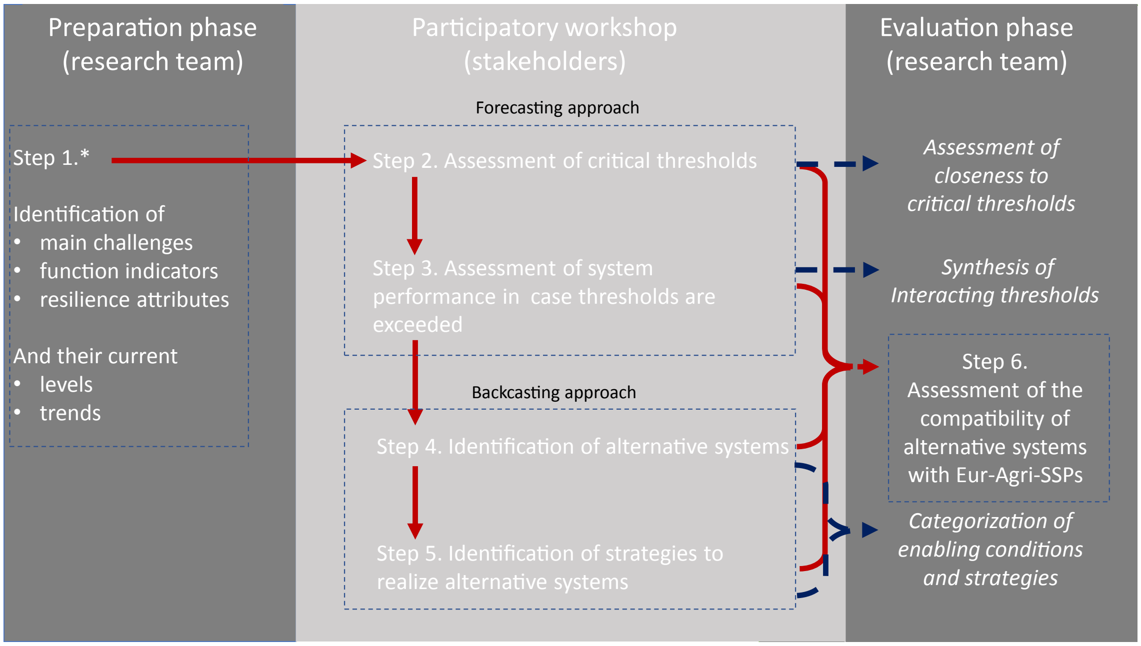


**Fig. 1.** Workflow of FoPIA-SURE-Farm 2 during the preparation phase, participatory workshop and evaluation phase. Parentheses at the top of each block indicate who does the action. Dashed arrows and italic font indicate the respective parts of Step 2–5 that are conducted in the evaluation phase. *Step 1 can be based on outcomes from FoPIA-SURE-Farm 1 (Paas et al., 2021) and/or other sources of information.

## 2. Methodology

### 2.1. FoPIA-SURE-Farm 2

The proposed methodology presented in this paper extends the Framework of Participatory Impact Assessment for Sustainable and Resilient EU farming systems (FoPIA-SURE-Farm 1) approach for assessing sustainability and resilience of *current* systems (Nera et al., 2020; Paas et al., 2021; Reidsma et al., 2020) with participatory assessments on resilience of EU farming systems in the *future* (FoPIA-SURE-Farm 2). FoPIA-SURE-Farm 1 and 2 are based on the SURE-Farm resilience framework (RF; Meuwissen et al., 2019): 1) defining and delineating the farming system, 2) identifying main challenges, 3) assessing farming system functions, 4) assessing the system's resilience capacities (robustness, adaptability and transformability), and 5) assessing the system's resilience enhancing attributes (system characteristics that convey resilience to a system). While FoPIA-SURE-Farm 1 was mainly aimed at performance levels of main indicators, that represent main functions of the system, and resilience attributes, FoPIA-SURE-Farm 2 includes resilience concepts such as critical thresholds, interactions between thresholds (e.g. Kinzig et al., 2006), and regime shifts (e.g. Biggs et al., 2018).

In this paper we define the basis of a farming system as the farms producing the main products of interest in a regional context. Farming system actors included in the farming systems are the producers of main products and other actors that mutually influence one another (Step 1 RF). The perceived complementarity of sustainability and resilience is operationalized by distinguishing system *challenges*, *function indicators* and *resilience attributes*. In the context of resilience, *challenges* relate to the question "resilience to what?", such as resilience to weather extremes (Step 2 RF). *Function indicators* are case-study specific representatives for important system *functions*, such as "Food production" or "Maintaining natural resources", as direct metrics for those *functions* are often not available (Step 3 RF; Table A1). In the context of resilience, *function indicators* relate to the question "resilience for what?". This relates to sustainability, which is defined as an adequate performance of all system *functions* across the environmental, economic and social domain (König et al., 2013; Morris et al., 2011; Paas et al., 2021). *Resilience attributes* are characteristics that convey general resilience to a system (Step 5 RF; Table A2). These *resilience attributes* can often be linked to system resources (Paas et al., 2021), e.g. natural or social capital, that can only be maintained when system *functions* are performing adequately. To improve the flexibility of the methodology and the clarity and saliency of participatory input, just like for *functions*, case-study specific indicators may be used for *resilience attributes*, as well as for *challenges*. Based on workshop results, inductions are made about the resilience capacities of the studied farming system (Step 4 RF). For more details on the concepts used in this study, see Appendix A.

FoPIA-SURE-Farm 2 consists of a preparation phase, a participatory workshop and an evaluation phase, and was developed for application and comparison across 11 EU farming systems (Paas et al., 2020) (Fig. 1). In this paper we present six key steps of the methodology (Fig. 1). In Step 1, current performance and trends of *function indicators* and *resilience attributes* are assessed by the research team in the preparation phase. This assessment can be largely based on FoPIA-SURE-Farm 1 (Paas et al., 2021; Paas et al., 2019), but other (grey) literature can also be used. In Step 2, critical thresholds of important system *challenges*, *function indicators* and *resilience attributes* are assessed by workshop participants. Based on Biggs et al. (2018) and Kinzig et al. (2006), we define critical thresholds as the levels at which *challenges, function indicators* or *resilience attributes* are expected to cause large and permanent system change. System's closeness to thresholds is consequently evaluated by the research team based on participants' comments and (grey) literature, e.g. based on ongoing trends identified in Step 1. In Step 3, performance of main *function indicators* and *resilience attributes* is assessed when critical thresholds of main *challenges* would be exceeded. Possibilities of interacting thresholds can be discussed during the workshop and in the evaluation phase, following the framework of Kinzig et al. (2006). Interacting thresholds are thresholds, that, when exceeded, lead to the exceedance of another threshold, i.e. there are cascading effects. In summary, Step 1, 2 and 3 provide an overview of possible system performance in case no adaptations for improved sustainability and resilience are made.

Keeping the sustainability and resilience of the current system and the impact of exceeding critical thresholds as a point of reference, Step 4 addresses possible desired changes of the farming system towards the future. Participants can indicate and discuss what alternative systems are possible when *challenges* would become more severe, and when/how certain *function indicators* and *resilience attributes* would improve compared to the current system configuration. Step 5 aims to gain information on the strategies that are needed to realize alternative systems. We indicate these strategies as "future strategies". Steps 2 to 5 correspond largely to the participatory workshop phase. In the workshop, individual, break-out and plenary sessions are alternated. Individual and break-out sessions are included to ensure that all participants can provide input, which can be used as input for further discussions in plenary sessions. The proposed session format in each step can be changed according to needs of the participants, as long as a balance between individual, break-out and plenary sessions is maintained. In Step 6, in the evaluation phase, researchers evaluate whether desired future systems, i.e. the current system maintained in the future and the alternative systems, are compatible with developments in Shared Social Pathways for European agriculture (Eur-agri-SSPs; Mitter et al., 2019; Mitter et al., 2020) and hence match exogenous developments at European level. The time horizon for the future is 2030 in all steps. In the next sections we present details of each of the six steps.

### *2.2. Current performance (Step 1) and critical thresholds (Step 2)*

A pre-selection is made of most important system *function indicators* and *resilience attributes*, their qualitative description of performance (very low, low, moderate, good, very good performance) and developments (no change, strong or moderate negative or positive change) (Step 1). Step 1 can be based on FoPIA-SURE-Farm and/or other information sources. Participants individually evaluate the existence of critical thresholds related to *function indicators*, *resilience attributes* and *challenges* (Step 2). Walker and Salt (2012) mention that it is impossible to determine critical thresholds for *resilience attributes* because they all interact. However, we include *resilience attributes* as it stimulates thinking about resilience. Moreover, participatory input on thresholds can be interpreted as formulations of potential concerns for which management goals and strategies may be developed (Walker and Salt, 2012). In plenary sessions, individual input is discussed. Participants are free to discuss and conclude on the relative closeness of their system to critical thresholds. In case closeness of the system to critical thresholds is not indicated by participants, the research team evaluates closeness based on the current performance levels, and magnitude of variation and/or trends. "Not close", "somewhat close" and "close" to thresholds are defined as respectively unlikely, somewhat likely and likely that the distance to critical thresholds will be trespassed in the coming ten years, based on knowledge on possible variation and/or trends. A fourth category is identified as current levels being already at or beyond the critical threshold ("at threshold or beyond").

### *2.3. What if thresholds of challenges are exceeded? (Step 3)*

Per identified main *challenge*, it is evaluated in a participatory forecasting approach what the effect of a change beyond the indicated thresholds would be on main indicators and *resilience attributes* (Step 3). For this, the group is split in small groups of participants, each discussing one *challenge*. First, the expected direction of change of the *challenge* is clarified. Secondly, the relation between *challenge* and *function indicator* or *resilience attribute* is discussed. In each group, a moderator synthesizes this with a score of –, -, +-, + and ++ alongside arrows from *challenges* to *function indicators* and *resilience attributes*. A + relation implies that if the level of the *challenge* increases, the *function indicator* or *resilience attribute* also increases (i.e., a decrease in the level of the *challenge* also leads to a decrease in the *function indicator* or *resilience attribute*). Verifications are also made in relation to possible interactions among and between *function indicators* and *resilience attributes*. Optionally, the expected impact on the *function indicator* or *resilience attribute* is indicated. This impact is scored referring to the expected performance level from 1 to 5, similar to FoPIA-SURE-Farm 1 (Reidsma et al., 2019). In a plenary session, each moderator feeds back the results of the small group in a 1-minute pitch, after which participants can respond.

Based on the outcome of questions on critical thresholds and forecasting the impacts of exceeding them, the possibility of interacting critical thresholds is evaluated by researchers in the evaluation phase using the framework of Kinzig et al. (2006). Kinzig et al. (2006) specifically assess critical thresholds and cascading effects across scales for alternative future states of agricultural regions. Kinzig et al. (2006) distinguish the ecological, as well as the economic and social/cultural domain across the patch, farm and region scale. Thresholds of systems parameters can interact across domains and levels of integration (Kinzig et al., 2006). A good balance between developments in the different domains and levels may improve sustainability and resilience of a system (Walker and Salt, 2012). In systems with strong interactions between system variables at lower levels, vulnerability of the system at the focal level may increase (Resilience Alliance, 2010). This is especially the case when variables at lower levels are all aligned with regard to their closeness to critical thresholds (Resilience Alliance, 2010). An (almost) simultaneous exceedance of critical thresholds at lower levels may result in further cascading effects and ultimately result in an alternative, undesired system state at focal level, which in this study is the farming system. In the context of this paper we distinguish the environmental, economic and social domains and the field, farm and farming system levels.

### *2.4. Desired transformations of the farming system (Step 4)*

In a forecasting approach for improved sustainability, results are largely based on dominant trends and causal mechanisms that often lead to low sustainability. Solutions for improved sustainability, therefore, ideally need to break these trends and causal mechanisms (Dreborg, 1996; Quist and Vergragt, 2006). In this part of the workshop, we therefore shift from a forecasting approach to a backcasting approach. A backcasting approach has greater problem-solving capacities in long-term challenges, because it is concerned less with what is likely to happen and more with what is desirable in the future (Quist and Vergragt, 2006). Picturing future systems may stimulate system actors to widen their perspectives and improve their understanding of the concept of sustainability (Dreborg, 1996). In this study, the backcasting approach is focused on alternative farming systems that have improved performance of *function indicators* and *resilience attributes* (Step 4).

To identify these alternative systems, all participants are asked to write on post-its alternative systems they desire if *challenges* cross thresholds and/or *functions* need improvement. This ensures that stakeholders can give their own input and are not directly influenced by others. If input is low, thinking can be stimulated among participants by presenting alternative systems that are identified by the research team in the preparation phase. Based on the post-its, several alternative future

**Table 1**
Main function indicators and resilience attributes performance in the current situation and developments of performance as expected for future systems (results based on Step 1-4 of the methodology). → implies no change, ↗moderate positive change, ↑ strong positive change, ↘ moderate negative change, ↓strong negative change. Arrows in bold font are results obtained in the workshop. Arrows in normal font are deductions made in the evaluation phase based on what has been discussed during the workshop.

| | | | | *Expected future developments* | | | |
|---|---|---|---|---|---|---|---|
| | | | | | | *Alternative systems (Step 4)* | |
| *Function (F)/ Resilience attribute (RA) / Challenge (C)* | *Indicator* | *Current level (Step 1)* | *Closeness to threshold (Step 2)* | *Current system (Step 1)* | *Critical thresholds exceeded (Step 3)* | *Semi-intensive system* | *High-tech extensive system* |
| *F: Economic viability* | *Gross margin* | ***Low*** | *(Somewhat) close* | → | ↘\|↓ | ↗ | ↗ |
| *F: Food production* | *Number of sheep* | ***Very low*** | *At threshold or beyond* | → | ↓ | ↗ | ↑ |
| *F: Quality of life* | *Number of farms* | ***Low*** | *At threshold or beyond* | ↘ | ↓ | ↗ | ↗\|→ |
| *RA: Production coupled with local and natural resources* | *Availability of pastures* | ***Low*** | *(Somewhat) close* | ↘ | ↘\|↓ | ↘ | ↑ |
| *RA: Diverse policies* | *Subsidies* | ***Low*** | *At threshold or beyond* | → | ↘\|↓ | ↘ | ↗ |
| *RA: Socially self-organized* | – | *Moderate* | *Not close* | → | ↘\|↓ | → | ↑ |
| *RA: Supports rural life* | – | *Low* | *Close* | ↘ | ↘\|↓ | ↗\|→ | ↗ |
| *RA: Infrastructure for innovation* | – | *Low* | *Close* | ↘ | ↘\|↓ | ↗ | ↗ |
| *RA: Reasonably profitable* | – | *Low* | *At threshold or beyond* | ↘ | ↘\|↓ | ↗ | ↗ |
| *C: Decreasing national lamb meat consumption* | *Consumption per inhabitant* | – | *At threshold or beyond* | – | – | – | – |
| *C: Increasing feeding costs* | – | – | *At threshold or beyond* | – | – | – | – |
| *C: Increasing wild life attacks* | – | – | *Not close* | – | – | – | – |
| *C: Lack of workforce* | *Workforce per farm* | – | *At threshold or beyond* | – | – | – | – |

systems are identified in a plenary session. These alternative systems may be combinations of suggestions of different participants. Some may be adaptations and some transformations of the current system. After giving them a name, per alternative system, one small group of participants is formed to further discuss which main *function indicators* and *resilience attributes* will change. In addition, changes in land use, sectors, objectives and other relevant aspects may be discussed. Participants in small groups also discuss the enabling conditions, i.e. how *challenges* and other drivers should change in order to be able to reach these alternative systems. Small groups consist of at least one moderator from the research team and three participants. In the evaluation phase, enabling conditions are categorized by researchers under the following domains: agronomic, economic, environmental, institutional, social.

### 2.5. Strategies to realize desired transformations (Step 5)

Taking alternative systems as the points of reference, the backcasting approach is continued by identifying strategies to realize the alternative systems, in the small groups. A strategy is seen and communicated to workshop participants as a "plan of action, or part of it, implemented by actors within and outside the farming system to maintain or reach a desired farming system in 2030". The workshops ends with a plenary session, in which participants are asked whether there is a shared vision about the future farming system. If such a shared vision is present, the discussion on the strategies to select is tailored towards this vision. If not, all possible alternatives and strategies are kept in mind. These strategies for future systems are compared with the strategies that have been implemented in the past and current system, as derived from FoPIA-SURE-Farm 1, to understand what should change.

### 2.6. Compatibility of future systems with Eur-Agri-SSPs (Step 6)

In the evaluation phase, carried out by researchers, the level of *functions*, *resilience attributes*, required strategies and enabling conditions in the different future systems are compared with future scenarios (Step 6). Future systems include the continuation of the current system in the future as well as the proposed desired alternative systems. As future scenarios we use the storylines of the Shared Socio-Economic Pathways adapted for European agriculture (Eur-Agri-SSPs; Mitter et al., 2019; Mitter et al., 2020). The five Eur-Agri-SSPs include: agriculture on sustainable paths (1), on established paths (2), on separated paths (3), on unequal paths (4) and on high-tech paths (5). Mitter et al. (2019); Mitter et al. (2020) take into account multiple indicators (Eur-Agri-SSP-indicators) that are categorized under the themes "Population", "Economy", "Policies & institutions", "Technology" and "Environment & natural resources". Per Eur-Agri-SSP-indicator researchers indicated how important an increase of this indicator is for the alternative system, where 0 is "not important", 1 is "somewhat important" and 2 is "very important". Expected developments of SSP-indicators are taken from Mitter et al. (2020), where ↘,→ and ↗ were translated into the values −1, 0 and + 1, indicating negative, no and positive changes, respectively. Multiplication of importance of positive developments for future systems {0; 1; 2} with expected developments of Eur-Agri-SSP-indicators {-1; 0; 1} is used as an approximation for compatibility. If, for instance, natural resources need to improve in a certain alternative system, this is aligned with the improvements foreseen for the Eur-Agri-SSP-indicator "natural resource management" in the sustainable paths scenario. This makes the alternative system and this scenario compatible, at least for this specific Eur-Agri-SSP-indicator. In a next step, compatibility scores are aggregated and transformed (sum of the compatibility scores divided by the sum of the importance scores) per theme (Population, Economy, etc.). Final compatibility scores per future system per Eur-Agri-SSP are an average of the overall section scores per theme, where values −1 to −0.66 imply strong incompatibility, −0.66 to −0.33 moderate incompatibility, −0.33 – 0 weak incompatibility, 0–0.33 weak compatibility, 0.33–0.66 moderate compatibility, and 0.66–1 strong compatibility.

## 3. Application to extensive sheep farming in Huesca, Spain

### 3.1. Case study description

The case study is the extensive sheep farming system located in the Huesca province, Northeast Spain. Huesca covers about 15,000 km$^2$ and two main regions can be distinguished: 1) The Pyrenees and pre-Pyrenees in the North, covering about 6,000 km$^2$, where agricultural activities are confined to extensive livestock; and 2) the southern part of the province, characterised by the plains of the Ebro depression (about 9,000 km$^2$), where extensive farming (sheep, goat and cattle), intensive farming (pigs and broiler) and crop farming (rainfed and irrigated) are present.

In Huesca, the number of (ovine and caprine) decreased from 2,902 (1995) to 1,018 (2019) and the number of sheep from 923,399 (2005) to 521,501 (2019) (Gobierno de Aragón, 2019; Gobierno de Aragón, 2016; MAPA, 2019a). The size of farms has shown an upward trend in the last years. The current size of a herd is between 200 and 1,000 sheep (Gobierno de Aragón, 2019). These trends are a result of the convergence of a range of economic, institutional, social and environmental *challenges* the farming system is facing. The extensive sheep farming system is highly dependent on EU and national subsidies, and hence, vulnerable to changing agricultural policy goals and increasing bureaucracy and control requirements. Regarding the social *challenges*, the case study area suffered a vast population decline over the last century (Bosque and Navarro, 2002) that comes along with a lack of skilled labour, social services and infrastructures. The low attractiveness of the farming system and the agricultural specialization result in the lack of new entrants. Finally, the extensive sheep farming system is increasingly limited in the access to pastures. The strategies that farmers have been implementing over time to deal with these *challenges* follow four management patterns, i.e. intensification, extensification, diversification and conservation (Bertolozzi-Caredio et al., 2021).

In addition to the provision of private goods, such as to ensure sufficient farm incomes and deliver high-quality food at affordable prices the extensive farming system also provides public goods. Grazing helps to maintain and preserve the natural resources contributing to keep soil quality (Peco et al., 2017) and biodiversity by maintaining landscape heterogeneity (Ornai et al., 2020; Rodríguez-Ortega et al., 2014; Silva et al., 2019). Extensive livestock activity is also important to prevent forest fires by keeping the area clean from dry biomass (weeds and scrubs), which act as fuel in Mediterranean areas (Casasús et al., 2007; Ruiz-Mirazo and Robles, 2012). Grazing activities also provide recreational areas demanded by society (Bernués and Olaizola, 2012) and keep the rural areas attractive. As a result of the *challenges* mentioned in the previous paragraph, levels of *functions* in the farming system are generally perceived to be low (Becking et al., 2019; Reidsma et al., 2020).

The clear presence of interacting economic, social and environmental domains makes the extensive sheep farming system in Huesca, an interesting case study for studying sustainability and resilience. In addition, there are signs of low sustainability, low resilience and consequently a pending decline of the farming system (Becking et al., 2019). The FoPIA-SURE-Farm 2 workshop was conducted on 14 February 2020 from 9.00 am till 3.00 pm with one break in the middle and lunch at the end. Eighteen people participated in the workshop, of which seven were farmers (five of the seven farmers belonged to an 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)).

### 3.2. Current sustainability and resilience performance (Step 1)

Participants agreed with FoPIA-SURE-Farm 1 results (Becking et al., 2019) on current performance of main indicators related to the *functions* of ensuring economic viability, food production and quality of life: gross margin, number of sheep and number of farms, respectively (Step 1). Two main *resilience attributes* discussed in the workshop were 'production coupled with local and natural capital' and 'diverse policies' (see also Tables B1 and B2, Appendix B). As proxies for those *resilience attributes*, "availability of pastures" and "subsidies" were used, respectively, to ease the communication. The current performance of *function indicators* and presence of resilience attributes was considered low, with no change or moderately negative change (Table 1; 3rd column).

### 3.3. Critical thresholds (Step 2)

When discussing critical thresholds (Step 2), participants argued that these were already reached and that the farming system was on the edge of collapse/decline (Table 1). When participants resisted to participate individually, the flexibility of the methodology allowed for slightly adapting the procedure in Step 2[1]. In order to stimulate the discussion and obtain values for thresholds, the trend and current value of the indicators according to the official statistics were presented to participants. In case of disagreement, participants were asked to define the current value of the indicators in a plenary session, which helped the researchers to determine how the discussed values were more or less close to the threshold. Based on the plenary discussions on thresholds, researchers deduced a number of enabling conditions that are needed to maintain the current system in the future. In the next sections, actual levels, developments and threshold levels of *function indicators*, indicators of *resilience attributes* and *challenges* are presented.

#### 3.3.1. Main functions and related indicators

*3.3.1.1. Economic viability: Gross margin.* Participants indicated that the gross margin is the decisive variable that determines whether the farming system is on the edge of collapse or not. Participants indicated that the gross margin threshold of the farms is 25–30 €/head. According to the literature, gross margins in the farming system vary among farms depending on feeding costs, size of herds (Milán et al., 2003; Pardos et al., 2008) and aids (Bernués and Olaizola, 2012; De Rancourt et al., 2006). This implies that not every farm is similarly close to the gross margin threshold. While the gross margin of the farms in the flat areas is at threshold and beyond (25–30 €/head), the distance of gross margins to the thershold appears larger in the farms located in the mid-mountain areas (40-45€ (MAPA, 2017)). The latter have lower feeding costs than the former because the herd feeding relies almost enterely on the availability of pastures. Herd size in mountain areas used to be higher allowing farmers to benefit from economies of scales. Farmers in mountain regions also receive least favoured area aids that increase their income.

*3.3.1.2. Food production: Number of sheep.* Participants agreed that the current number of sheep has reached the tipping point in the area. There are currently about 521 thousand sheep heads in the province of Huesca, with a reduction of 43.7% since 2005 (Gobierno de Aragón, 2019; MAPA, 2019a). The decrease in the number of sheep in the farming system has not been as sharp as that of the number of farms. The reason that the decrease of sheep number has not been so marked in the last 10 years is because herds of quitting farms have been acquired by the farms that stayed.

The strategy of buying sheep from quitting farmers allowed other farmers to increase their margins and remain in the farming system. Pardos et al. (2007) found an average increment of 85 sheep per farm

[1] Due to the perceived closeness to critical thresholds in the studied system and participants' subsequent difficulty in following the normal procedures, the flexibility of the methodology was used to adapt procedures. While adapting the procedures, a balance between individual, small group and plenary activities was maintained to improve the chances that all participants could provide their input.

from the period 1996–2001 to period 2002–2005. Currently, farmers are investing a great effort and time managing between 500 and 1,000 sheep/shepherd, but the gross margins are not enough to hire new shepherds and increase the herd. Consequently, from now on the number of sheep is expected to decrease with each farm disappearing from the system.

*3.3.1.3. Quality of life: Number of ovine farms.* Providing quality of life by means of creating rural employment with decent working conditions came up as one of the main *functions* of the farming system. This *function* is measured by the number of farms, as suggested by researchers and agreed upon by participants. Creating rural jobs contributes to keeping the rural areas attractive for residence and tourism. As also indicated by participants, the rural depopulation is an important challenge that this farming system has been facing since the last century (Bosque and Navarro, 2002). The depopulation seems to have more to do with the general socio-economic context of the farming system (lack of workforce, migration to urban centers, etc.), than with the sheep farming system itself (Bernués and Olaizola, 2012). The number of farms has decreased by 65% in the period 2005–2019, to the current value of 1,018 (Gobierno de Aragón, 2019; Gobierno de Aragón, 2016), which is considered to be at the threshold or beyond.

### 3.3.2. Main resilience attributes and related indicators

*3.3.2.1. Coupled with local and natural capital: Availability of pastures.* All participants agreed that the costs of feeding are strongly related to the availability of pastures. During the workshop, availability of pastures was assessed by looking at the total available surface of pastures (ha). In the province of Huesca the total amount of pastures has decreased by 65% in the period 2003–2018, with a current total of 160,000 ha in the province of Huesca (MAPA, 2019b). Participants concluded that the availability of pastures meets the farming system's needs, especially now the number of sheep has decreased.

However, in some areas such as the flat areas and those surrounding the Natural Parks and other protected areas (*Sierra y Cañones de Guara* Natural Park), the access to pastures is limited or nil. Although grazing contributes to modulate the vegetation dynamics (Bernués et al., 2005), bureaucracy and regulations limit the access to the pastures in the protected areas. Simultaneously, the increasing intensification of the agriculture in the flat areas is limiting the area of grazing lands. Moreover, the intensification of the farming system has led to the abandonment of lands, mainly in the mid-mountain areas. This abandonment causes a simplification and homogenization of the landscape due to the increase of the tree and shrub stratums, which lead to decrease in biodiversity and increase of fires (Lasanta-Martínez et al., 2005; Vicente-Serrano et al., 2000). Participants found it difficult to provide a minimum value of pasture surface they need for grazing, but they pointed out that the authorities must ease the access to pastures as well as compensate for environmental services delivered by the ovine farming system. Based on the input from participants, the research team estimated that the system is somewhat close to a critical threshold regarding the availability of pastures.

*3.3.2.2. Diverse policies: Subsidies.* Participants explained that if basic payments would be lower than the current level, the gross margin would be null or negative, indicating that a critical threshold is reached. Farmers' incomes in the extensive sheep farming indeed depend greatly on aids (Bernués and Olaizola, 2012; De Rancourt et al., 2006). The basic payments was around 24 € per sheep (MAPA, 2019c). Participants claimed that payments should increase at least by 30% to reach suitable gross margins. In fact, the decoupling of aids and the Common Agricultural policy (CAP) modulation have reduced the farms' income (Pardos et al., 2008).

### 3.3.3. Challenges

*3.3.3.1. Lowering national lamb meat consumption.* According to participants, the lamb consumption should not decrease more than the current level, indicating that the current level in fact is the critical threshold. Lamb meat consumption has declined strongly in the period 2006–2019 (50% of reduction), with a current value of 1.3 kg/inhabitant/year (MAPA, 2020). Participants mentioned that in the short term this *challenge* has a negative influence on the gross margin and the number of sheep, whereas, in the long term, it can lead to the closure of farms.

Participants identified several drivers that explain the lowering demand: consumers preferring other type of meats, mainly pork and chicken; disappearing culinary traditions; upcoming vegetarian and veganism trends; and the increasing campaigns against livestock farming influencing the negative perception of the sheep farming system (Appendix C). Overall, decreasing demand is indeed related to urban trends (Martin-Collado et al., 2019) and social-economic conditions such as consumer preferences and family structures (Corcoran, 2003). The quality of products from the case study area may give a competitive advantage (Bernués et al., 2006).

*3.3.3.2. Increasing feeding costs.* The feeding costs are a key element in the gross margin per head and at or beyond a critical threshold according to workshop participants. According to MAPA (2019c), the current average value of the feeding costs is about 30€ per sheep in extensive sheep farms in Aragon. Participants agreed with this current value. According to Pardos et al. (2008) feeding costs depend on the type of farm. Intensive farms implementing feeding practices that rely more on feeds will deal with greater feeding costs (20–30 €/head) than extensive farms that rely more on the availability of pastures (14–17 €/head).

Droughts have been increasing in the last years (Hernández-Mora et al., 2012; Turner, 2004). Droughts are an important driver for increasing feeding costs, especially for those farms highly dependent on the availability of pastures for feeding the herds. For example, to overcome the low productivity of pastures caused by droughts in 2019, the European Commission allowed grazing in ecological focus areas (EFA) in Andalucía (Commission implementing decision (EU) 2019/1389, of 4 September 2019).

*3.3.3.3. Increasing wild fauna attacks.* Participants in the workshop are extremely worried about the increasing number of wolves and bears. The wild fauna attacks are recent and there are no clear statistics, but there is great concern about the potential impact. Participants did not provide the value of a critical threshold for wild fauna attacks in the ovine farming system. They indicated that the wild fauna attacks are more frequent in the mid-mountain than in the flat areas, where the attacks rarely occur. Participants mentioned that the attacks not only negatively affect the profitability of the farm, but also the farmers' quality of life (Table C3) as attacks imply more time and investments to take care of the herd. Based on the input from participants, the research team estimated that the system is not close to a critical threshold regarding wild fauna attacks.

*3.3.3.4. Lack of workforce.* The Annual Work Unit (AWU) per farm has shown a downward trend over the last years. The current value in the farming system is 1.9 AWU per farm. Participants agreed that this current value is the critical threshold for the workforce in the farming system. The low farm margins do not allow farmers to offer attractive labor conditions and hire personnel. Farmers run the farm alone or with family support. The socio-economic context of the farms such as the distance to major cities and the availability of public services in rural areas also explain the lack of workforce (García-Martínez et al., 2009).

The AWU per farm indicator is also indicative for the quality of life. A decrease in the AWU/farm value indicates a greater workload by the person(s) running the farm. Participants mentioned that the ovine farming system is very time consuming, mainly due to the shepherding. Shepherding is conditioned by the availability of pastures. In several occasions, pastures are far away from farms and farmers need to move long distances with the herds, spending a lot of time far from their families. The low number of shepherds limits the options to cooperate in shepherding and get time free.

### 3.4. Assessing the impact of exceeding critical thresholds (Step 3)

To compensate for the plenary input in Step 2, the research team decided that each participant should individually assess the impact when critical thresholds are exceeded (Step 3). In a plenary session all participants discussed the effects of exceeding critical thresholds of *challenges* and interactions between critical thresholds. Overall, exceeding the critical threshold of one of the *challenges* was expected to lead to moderate to strong decline in performance of main *functions* and *resilience attributes* (Table 1). Plenary discussion results are presented in detail in Appendix C.

In the evaluation step, interactions of thresholds across domains and scales (Fig. 2) resulted in a vicious circle which explains the expected decline in system functioning when critical thresholds are approached and exceeded (Table 1). To adequately describe interacting thresholds in Fig. 2, some additional indicators were added that came forward during the discussions with stakeholders. Fig. 2 can be read as a summary of the information provided in the previous sections on thresholds of main *function indicators*, *challenges* and *resilience attributes*. Gross margin, a main *function indicator* of the system, plays a pivotal role in the interaction of thresholds and affects the number of farms and consequently the number of sheep in the area. Gross margins are directly affected by three main *challenges*: reducing subsidies, decreasing consumption and increasing feeding costs. Reducing gross margins and the closure of farms further reduces the available workforce, which reinforces the

**Table 2**
Relevance of enabling conditions categorized per domain. V implies that an enabling condition is relevant for maintaining the current system in the future and/or moving to an alternative system. Tick marks in bold font are results obtained in the workshop. Tick marks in normal font are deductions made in the evaluation phase based on what has been discussed during the workshop. FS: farming system.

| *Domain* | *Enabling conditions* | *Current system* | *Alternative systems (Step 4)* | |
|---|---|---|---|---|
| | | | *Semi-intensive system* | *High-tech extensive system* |
| *Agronomic* | *New technology applied to sheep FS farm management* | – | ***V*** | ***V*** |
| *Agronomic* | *Farmers training in new technology* | – | ***V*** | ***V*** |
| *Agronomic* | *Improved sanitary conditions* | *V* | ***V*** | ***V*** |
| *Agronomic* | *Improved animal handling* | *V* | ***V*** | ***V*** |
| *Agronomic* | *Geo-localization technology* | – | – | ***V*** |
| *Agronomic* | *Use of sub-products* | – | ***V*** | – |
| *Economic* | *New financial products* | *V* | ***V*** | ***V*** |
| *Economic* | *New commercialization channels and market niches* | *V* | ***V*** | ***V*** |
| *Economic* | *Public aids for public goods provision* | *V* | – | ***V*** |
| *Environmental* | *Broader access to pastures and stubble fields* | *V* | – | ***V*** |
| *Environmental* | *Sustainable pastures management* | *V* | – | ***V*** |
| *Environmental* | *Research relationship nature-ovine FS* | – | *V* | ***V*** |
| *Institutional* | *Reduced bureaucracy control* | *V* | ***V*** | ***V*** |
| *Institutional* | *FS oriented legislation (sanitary, environmental and urban)* | *V* | ***V*** | ***V*** |
| *Institutional* | *Rural development* | *V* | – | ***V*** |
| *Social* | *Public awareness of the contribution of FS* | *V* | *V* | ***V*** |
| *Social* | *Improved cooperation among actors* | *V* | – | ***V*** |

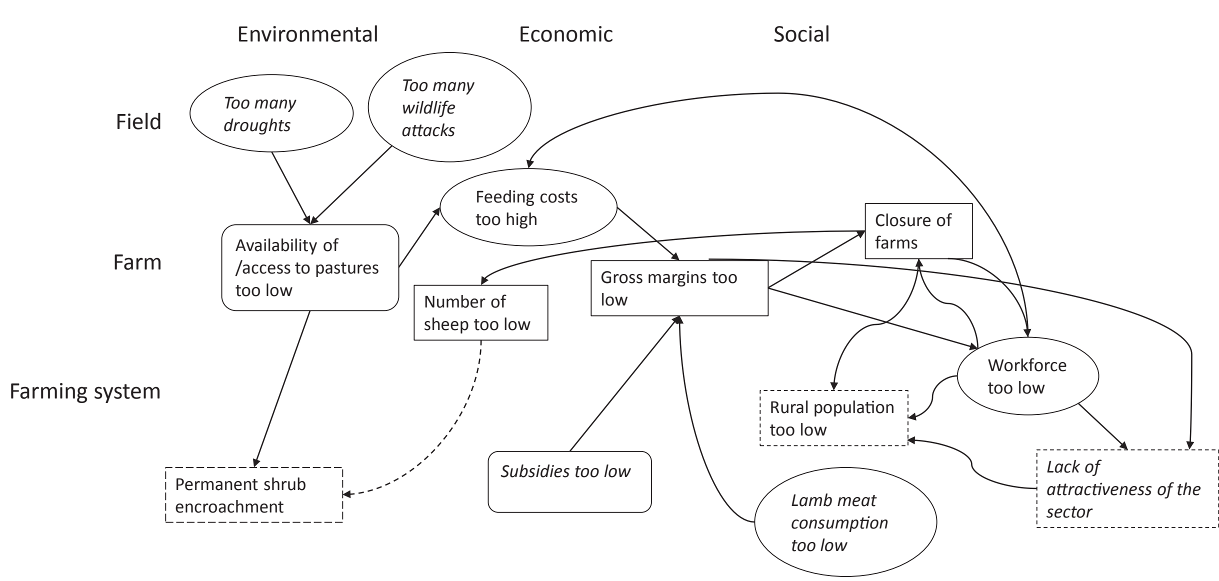


**Fig. 2.** Interacting thresholds between levels and domains for function indicators (rectangular shapes with sharp edges), indicators of resilience attributes (rectangular shapes with rounded edges), challenges (oval shapes) and additional indicators (rectangular shapes with dashed lines).

**Table 3**
Current strategies and future strategies for different future systems. Current strategies are based on FoPIA-SURE-Farm 1. Strategies proposed for future systems that are currently being implemented are underlined. Current strategies (not explicitly indicated in the workshop for future systems) are indicated in italics. Strategies in normal font are the strategies that were proposed for future systems and that are not implemented in the present. Bold font checks indicate that these strategies were mentioned during the workshop for a specific system. Normal font checks indicate that, based on the discussions during the workshop, it seems likely that strategies will be applied in certain systems. FS: farming system.

| Strategy | Domain | Current system | Future systems: Semi-intensive system | Future systems: High-tech extensive system |
|---|---|---|---|---|
| Use of technology for management efficiency improvement (electronic readers, blood test, etc.) | Agronomic | | **V** | **V** |
| Research in more prolific and productive breeds | Agronomic | V | **V** | |
| Research for sanitary conditions of the ovine FS (new vaccines, medicaments, etc.) | Agronomic | | **V** | **V** |
| Implementation of sanitary conditions (hygiene, spaced animals, etc.) | Agronomic | V | **V** | **V** |
| Use of technology for animal positioning (GPS, mobile phone, etc.) | Agronomic | | | **V** |
| Farmers training in new technology | Agronomic | | **V** | **V** |
| Financial products to cover market volatile prices | Economic | V | **V** | |
| Financial products to cover droughts | Economic | V | | **V** |
| Opening up a foreign market | Economic | V | **V** | **V** |
| Boosting of local consumption | Economic | V | | **V** |
| Openness of local slaughterhouses | Economic | | | **V** |
| Diversification (on-farm) | Economic | V | **V** | |
| Alternative income sources (off-farm) | Economic | V | | **V** |
| *Investment in the farm assets* | Economic | V | V | V |
| *Costs reduction and flexibility* | Economic | V | V | V |
| *Sales contracts* | Economic | V | V | V |
| *Access to market information* | Economic | V | V | V |
| Improvement of the access to pastures and stubble fields | Environmental | | | **V** |
| Use of technology for control of grazed pastures | Environmental | | | **V** |
| Research in methane emissions from ovine FS | Environmental | | **V** | **V** |
| Use of technology for real-time communication with administration | Institutional | | **V** | **V** |
| Trained administration staff in FS specificities | Institutional | | **V** | **V** |
| Reduction of bureaucracy and excessive and specific regulations | Institutional | | **V** | **V** |
| Tailored legislation in environmental management | Institutional | | | **V** |
| Tailored legislation in sanitary conditions | Institutional | | **V** | **V** |
| New urban legislation | Institutional | | | **V** |
| Remuneration to the FS for contribution to public goods | Institutional | | | **V** |
| Improvement of legislation in relation to wild fauna | Institutional | V | | **V** |
| Innovation of laws for products origin and certification | Institutional | | V | **V** |
| Promotion of generational renewal (early retirements, access to land, etc.) | Institutional/ Social | | **V** | **V** |
| Creation of shepherd schools | Institutional/ Social | | | **V** |
| Promotion of lamb meat consumption | Institutional/ Social | V | **V** | **V** |
| Promotion of local breeds outside the FS | Institutional/ Social | | | **V** |
| Improvement of awareness of FS contribution to public goods | Institutional/ Social | V | V | **V** |
| *Associations and cooperatives* | Social | V | V | V |
| Improvement of quality of life (work intensity reduction with technology) | Social | V | **V** | **V** |

closure of remaining farms directly and indirectly via increasing feeding costs, which is why a lack of labor is seen as a main *challenge*. The *challenge* of increasing feeding costs is indirectly affected by increasing occurrence of droughts and wild fauna attacks, two other identified *challenges*. These *challenges* reduce the access and use of pastures, a proxy for the resilience attribute “production being coupled with local and natural capital”. Reduced access and use of pastures is eventually leading to shrub encroachment. Shrub encroachment is further stimulated when the number of sheep becomes insufficient to graze all available pastures. From a social perspective, the closure of farms and the decreasing workforce is expected to lead to a decreasing rural population.

### 3.5. Alternative systems (Step 4)

Instead of providing defined alternative systems on post-its, participants proposed ideas in a plenary session, thus using the flexibility that the methodology is offering. Two main alternative systems, their goals, *functions* and *resilience attributes* (Table 1) and enabling conditions (Table 2) came up in the brainstorming.

The first alternative system is the *semi-intensive system*. The main goal in this system is to improve the provision of private goods, i.e. increased

**Table 4**
Compatibility of the current system and alternative systems with different Eur-Agri-SSPs. With values −1 to −0.66: strong incompatibility, −0.66 to −0.33: moderate incompatibility, −0.33 – 0: weak incompatibility, 0–0.33: weak compatibility, 0.33-0.66: moderate compatibility, and 0.66–1: strong compatibility.

| Future systems | Eur-Agri-SSPs<br>1: Sustainable paths | 2: Established paths | 3: Separated paths | 4: Unequal paths | 5: High-tech paths |
|---|---|---|---|---|---|
| Maintaining the current system | 0.51 | 0.32 | −0.83 | 0.14 | 0.21 |
| Semi-intensive alternative system | 0.63 | 0.66 | −0.62 | 0.35 | 0.38 |
| High-tech extensive alternative system | 0.73 | 0.43 | −0.70 | 0.07 | 0.16 |

meat production and improved labor conditions. Several enabling conditions at farm level were identified to reach this end (Table 2). This alternative system would fit better in the southernmost and flat areas where crop diversification is easier to implement.

The second alternative system is the *high-tech extensive system*. The aim is to improve farms' profitability by reducing feeding costs based on an improved pasture management. Participants highlighted the need for the innovation in herd geo-location, weather information and wild fauna surveillance (Table 2). In addition, subsidies are essential in this system to support the provision of public goods as well as a legal framework to regulate and protect the access to land for grazing purposes. This alternative system would be more suitable in the northernmost and mountainous locations, where there are more pasturelands and geography makes other types of farming systems less appropriate.

Current *challenges*, such as the reduced consumption of lamb meat by consumers, the lack of workforce and the increasing feeding costs, are still important in the future alternative systems. The feeding costs are more important in the semi-intensive alternative system due to a greater dependency of feed inputs (fodders) and lower dependency on the availability of pastures. On the other hand, wild fauna attacks will only pose a *challenge* in the high-tech extensive alternative system. In the alternative systems, all main *functions* are expected to increase in a moderate way (Table 1). The gross margins would increase in both systems, although margins seem to differ depending on the degree of intensification or extensification of the farms, as well as the areas where the farms are located. The increase in gross margin in both systems is the main change that is expected to allow to increase the number of sheep and farms, and are therefore moving away from other critical thresholds as well. The location of the farm determines the agro-ecological potential and the access to markets (Geoghegan et al., 1997). Thus, the semi-intensive alternative system is more likely in the flat areas where pastures are more scarce and payments for the less favorable areas are not applicable (Pardos et al., 2008). In the high-tech extensive alternative system, the production is not expected to change. However, its performance in less favored areas (mid-mountains) and the provision of public goods services is supported by European subsidies that could increase the current margins. Greater gross margins would lead to a greater number of farms in the farming system, although this increase would be limited by the access to lands in the high-tech extensive system. The increase of the number of sheep is expected in both alternative systems, although this increment would be greater in the high-tech extensive alternative system. According to participants the lower production in this system would be compensated with greater herd sizes.

While some *resilience attributes* of the farming system ("infrastructure for innovation", "reasonable profitable" and "supports rural life") are expected to improve in both alternative systems, participants agreed that all the *resilience attributes* of the FS could improve in the high-tech extensive system (Table 1). The "social self-organization" *resilience attribute* in the high-tech extensive system would be improved as cooperation is needed to manage pastures and herds; it can also be argued that "production coupled to the local and natural capital" will improve as herd feeding will be coupled to the availability of pasture lands; and "diverse policies" will be enhanced as new policies will be tailored to support the provision of the public goods provided by the farming system. Moving towards the semi-intensive alternative scenario could constrain the *resilience attributes* "production coupled to the local and natural capital" and "diverse policies" leading to a deeper unbalance between the economic, social and environmental dimensions.

### 3.6. Strategies (Step 5)

Several current strategies, with currently low implementation levels, could be enhanced in the alternative systems. Some current strategies (in italics in Table 3) are compatible with the alternative farming systems. These strategies are mainly oriented to the economic domain, specifically related to the on-farm economic administration (investments in farm, savings, sales contracts, etc.) (Soriano et al., 2020).

Moreover, there were several new strategies identified during the workshop that match with current strategies (underlined in Table 3). Most of these strategies are economic strategies such as opening new marketing channels and developing new financial products and sales contracts that contribute to increase the robustness of the farming system to face hard times. Some institutional strategies are related to the public awareness campaigns about the positive contribution of the extensive sheep farming system to nature conservation and health. In the system, public awareness is expected to stimulate lamb meat consumption, which results in improved incomes. Public awareness is also expected to improve regulations for improving management of pastures, which in turn could lead to even more public awareness.

Most of the strategies proposed in the workshop are applicable for both systems and are mainly related to the need for improved technologies and innovation (normal font in Table 3). The number of proposed strategies was higher for the high-tech extensive system. The extra strategies in this system relate to the environmental and social domains, due to its more environmental-based and social nature. Institutional changes need to be made that improve the access to lands and the management of pasturelands, and the recognition of the farming system's contribution to the conservation of natural resources. This is expected to pay off in the economic domain, through subsidies and the lower feeding costs due to the use of pastures. Social measures are related to the promotion of generational renewal, which would increase the workforce in the farming system. The workforce availability improves the farmers' quality of life, stimulating the attractiveness of the farming system.

The quality of life is also improved with the implementation of new technology related to management of pastures and animal handling – in the semi-intensive alternative system the animal handling strategies are very important, mainly related to sanitary and production issues. The technology and innovation requires the cooperation between different actors in the exchange of knowledge and training in the technology (i.e., shepherds schools and GPS training in the high-tech extensive alternative system, and the management of more prolific breed and implementation of sanitary measures in the semi-intensive alternative system). The cooperation between farmers is also expected to increase the bargaining power and margins.

In any case, strategies regarding innovation and cooperation among system actors would be necessary, no matter what future system unfolds (no-regret strategies). It should be noted that the import of feed in the semi-intensive system reduces the coupling of production with local and natural resources. This could result in an opposite direction where, because of a worsening public image, less meat is consumed and regulations are getting stricter.

In both alternative systems, several strategies are oriented to technology implementation. The implementation of new technology generally does not allow for experimentation because of the great investments involved in new technology. For instance, in the high-tech extensive system the use of satellite images or the GPS per ewe is expensive. In the semi-intensive system, the replacement of more prolific ewes requires high investments. Strategies with low investment costs are related to the sanitary prevention, which lend robustness to the farming system (healthier animals that respond better to diseases), or the coordination among actors.

The probability of unfolding the high-tech extensive alternative system is expected to be larger than that of the semi-intensive system. The reason is that the semi-intensive system is going to compete with other intensive farming systems (e.g., pork) that are more profitable. The high-tech extensive system might highlight its importance in the contribution to the public goods and the conservation of the local breed *Rasa aragonesa*. As mentioned before, the greater availability of pastures makes the high-tech extensive system more suitable to mid-mountain areas. Farmers mentioned the high-tech extensive system as the preferable option in the future but also the most complicated to accomplish, especially without supporting policies in place. Besides, some of the technology for pasturelands and herds management is still in a development phase. In contrast, the lower presence (or absence) of pastures in flat areas of the farming system make the semi-intensive systems more appropriate in those areas. Participants pointed out that both alternative systems could attract young people to the farming system. Riedel et al. (2007) have related young farmers to a greater dynamism and technology adoption in the ovine production system and to the reduction of shepherding. Technology is indeed important in both alternative systems and (partly) replaces the need for actual shepherding.

### 3.7. Compatibility with Eur-Agri-SSPs (Step 6)

Based on the *challenges*, enabling conditions and strategies of the current and alternative systems, the extensive ovine farming system in the province of Huesca seems to be most compatible with a scenario on a pathway to higher sustainability with improved attention for the maintenance of natural resources (Eur-Agri-SSP1; Table 4), especially in the case of a high-tech extensive system. Compatibility with Eur-Agri-SSP1 is largely due to the increment of support for environmental services. As the current system is close to collapse, the compatibility with a scenario where the status quo is maintained as much as possible (Eur-Agri-SSP2) for the current state is limited. The establishment of the semi-intensive system is more compatible with Eur-Agri-SSP2 due to its production orientation. Eur-Agri-SSP3, with regional rivalry leading to amongst others slow technological process, is moderately to strongly incompatible with the current system and the alternative systems. In Eur-Agri-SSP3, specifically for the semi-intensive system, the lack of internationalization of markets, and for the high-tech extensive system the lack of environmental services valorization reduces compatibility. The semi-intensification of the farming system is evaluated as the only alternative system moderately compatible with Eur-Agri-SSP4, a scenario driven primarily by increasing social inequality, and Eur-Agri-SSP5, a scenario primarily driven by improvements in technology. The high-tech extensive system is even less compatible with Eur-Agri-SSP4 and Eur-Agri-SSP5 than the current system. Although the high-tech extensive system is most compatible with Eur-Agri-SSP1, the semi-intensive system seems the safest bet regarding its overall compatibility with all Eur-Agri-SSPs (for more detail see Appendix D and Appendix E).

## 4. Discussion

### 4.1. Insights from the case study

#### 4.1.1. Critical thresholds and impacts when exceeding these (Step 1–3)

The outcome of the workshop suggested that, currently, the social, economic and environmental performance of extensive sheep farming system in Huesca, Spain is poor and declining. This is a common trend in Europe. Strijker (2005) explained that increasing opportunities outside agriculture, lower product prices, and higher land prices explained the continuous decline of extensive livestock grazing systems in several rural areas across Europe. Bernués et al. (2011) found that the lack of generational succession and the high opportunity cost of labour are also drivers of the disappearance of livestock farming in European Mediterranean countries. Most *challenges*, system *functions* and *resilience attributes* seem to be at or beyond critical thresholds, indicating simultaneously low sustainability and low resilience levels. Interactions between critical thresholds of *challenges, functions* and *resilience attributes* across levels and domains are perceived to be present. This emphasizes the importance of including multiple levels and domains when studying the sustainability and resilience of farming systems. This also emphasizes the complementarity between sustainability and resilience, albeit in a negative sense. Overall, the effect of exceeding thresholds is expected to strongly reduce system performance in terms of sustainability and resilience. Economic viability at farm level plays a pivotal role regarding interacting thresholds. Participants indicated that exceeding the critical threshold for gross margin would result in a collapse of the farming system. This supports the idea that interacting indicators being close to critical thresholds at lower levels (field, farm) increase the vulnerability of the focal system (farming system) (Resilience Alliance, 2010). Interestingly, the level of gross margin is artificially maintained by subsidies that farms receive. This suggests a current focus on mainly economic sustainability, which in the long run may not be sustainable at all: subsidies may keep the fast responding "gross margin" away from critical thresholds, while the indicators relating to slower processes such as declining access to pastures in the environmental domain and lower attractiveness of the countryside in the social domain are not countered. Amalgamation of farms and livestock partly slows down the decline in sheep numbers and subsequent lower maintenance of the landscape. However, in the absence of subsidies and the limitations in managing huge herds, amalgamation is no longer profitable, which explains why participants expected a collapse. Biggs et al. (2018) mention that large shifts in socio-ecological systems are uncommon. The provisioning of agricultural subsidies could be seen as a main reason for continuing the status quo in some other agricultural systems in Europe as well. In the case of Huesca, change goes farm by farm, in terms of quitting and growing. However, there are limits to growth, relating to financial margins and availability of labour. Also the perspective of farmers that stay may change: it depends on how much the social fabric in a rural area is already eroded whether and how many farmers still can benefit from nearby facilities and off-farm work (Kinzig et al., 2006).

#### 4.1.2. Alternative systems, strategies and Eur-agri-SSPs (Step 4–6)

Strong feedback mechanisms from the environment to the farming system seem not to be perceived by farming system actors. This seemed also lacking in participants' mental models in other case studies where the methodology was applied (Paas et al., 2020). This lack may reveal the boundaries of local knowledge. Instead of feedback from the environment, "lamb meat consumption" and "regulations" are perceived to provide strong feedback signals: a low natural state of pastures and dependence on feed imports pays off negatively via the public image of the extensive sheep farming system, which in turn may lead to lower lamb meat consumption and stricter regulations regarding pasture management. These feedback loops are expected to stay important in both proposed alternative systems that stimulate economic viability in order to steer away from other thresholds. It could therefore be argued that the alternative systems are adaptations in reaction to *challenges* rather than transformations in which farming system structure and functioning changes radically. Bernués et al (2005) also found adaptation alternatives to reinforce the sustainability and resilience of the extensive farming systems. They proposed adaptations such as to define work organisation schemes that allow variations in labour needs, to explore the product mix that facilitates to transfer risks, and to increase the utilisation of on-farm resources (fodder and grazing) and the productivity (lambs per ewe or kg per lamb).

In the high-tech extensive system, more attention is given to landscape maintenance, which increases the number of enabling conditions and strategies compared to the semi-intensive system. For the high-tech extensive system this implies continued dependence on subsidies and in general more dependence on cooperation with actors inside and outside the farming system. The higher level of enabling conditions and strategies of the high-tech system compared to the semi-intensive system reduce the likelihood of matching all developments in each specific Eur-Agri-SSP, which is reflected in the reduced compatibility with most Eur-Agri-SSPs. On the one hand, this could be interpreted as having low resilience. On the other hand, the high-tech scenario moves towards an improved balance between economic, social and environmental *functions*. Improving this balance is suggested to improve general system resilience (Walker and Salt, 2012). The semi-intensive system seems more resilient regarding its higher compatibility with Eur-Agri-SSPs. However, focus in this alternative system is mostly on economic *functions*, which could undermine general resilience. Participants also perceived that this alternative system has less chances of being realized, as there is more competition over land with other farming systems, compared to the high-tech extensive system. In addition, lamb meat consumption and subsidies are expected to further reduce when production is becoming less pasture based. This leads to two methodological reflections. First, combining information on system trends and mechanisms, based on a forecasting approach, and requirements for realizing alternative systems based on a backcasting approach, shows the complementarity between the two approaches (Quist and Vergragt, 2006). Second, the local context seems very important when assessing compatibility of alternative systems with Eur-Agri-SSPs at farming system level. At the same time, the methodology raises awareness that depending on which scenario is unfolding, the local context may change, which could leave certain alternative systems unviable. Shifting between system and scenario perspectives thus provides a means to triangulate stakeholder input with researchers' perspectives.

### 4.2. Methodology

#### 4.2.1. A quick and flexible method

The proposed methodology provides a rapid and flexible way to assess multi-dimensional sustainability and resilience of future farming systems. Although qualitative in nature and covering many different topics, the methodology provides outputs that can be summarized and communicated in few key tables and a figure (Tables 1–4, Fig. 2). The concept of critical thresholds is key to stimulate participants to think about potential permanent and large changes in their system. The notion of interaction between critical thresholds stimulates participants to think about interactions between *challenges*, *functions* and *resilience attributes* in the social, economic and environmental domain. Rapid resilience assessments are not widely available (Nemec et al., 2014) and are often inferring resilience solely based on expected presence of *resilience attributes* (e.g. Nemec et al., 2014; Tittonell, 2020). Regarding the preparation phase, the method is flexible regarding the information sources used: results from FoPIA-SURE-Farm 1 or other sources of information. Other sources could be for instance (grey) literature, statistical databases and expert interviews. Provided time is managed strictly, the methodology turned out to be also flexible enough to be tailored to the local context and requirements with regard to changing individual, small group and plenary activities. Content-wise, the method also turned out to be agile with regard to including case study specific indicators, while the overarching concepts such as *functions* and *resilience attributes* allow for comparisons with other case studies. The same method was successfully applied in eight other SURE-Farm case studies in Europe (Paas et al., 2020), allowing, for instance, to compare critical thresholds across case studies. In two case studies, desk studies were performed based on the method (Accatino et al., 2020), also representing the flexibility of the method. Unfortunately, time-wise, the workshops did not allow for an extensive discussion of all relevant elements and topics. An extension of one hour to the workshop would enable a better discussion on strategies to realize alternative systems, e.g. by discussing the prioritization of strategies, which actors and what resources need to be involved to implement strategies (Mathijs and Wauters, 2020), and whether there are trade-offs among strategies.

#### 4.2.2. Influence of the research team

In case participants would not have assessed closeness to critical thresholds, the methodology suggests the research team to do this assessment. Such an assessment would be based on current levels and trends of main *function indicators*, *resilience attributes* and *challenges*. These levels and trends also serve as a points of reference (Table 1) and are based on previous work and other sources of information. This introduces an influence of the research team on the outcome of the workshop. Likewise, it should be noted that the method to assess compatibility of systems with scenarios, although transparent and useful for triangulating results, is also influenced by arbitrariness and subjectivity of researchers. For instance, when determining whether a development is important or very important for an alternative system, or when weighing the importance of the different groups of scenario indicators. The introduction of arbitrariness reduces the reproducibility of results. However, influence of researchers can also be explicitly accepted as a necessary part of an iterative, action-oriented process. In that process, researchers are actors aiming to develop, together with stakeholders, a shared, multi-dimensional understanding of current and future system performance (Wittmayer and Schäpke, 2014).

#### 4.2.3. Participation and influence

The proposed methodology in this paper is designed to provide a voice to individual stakeholders as well as give room to develop a common understanding and vision for the studied farming system. Working with (a limited number of) participants also brings in subjectivity and arbitrariness. Suggestions from participants to make individual exercises plenary in this Spanish application may be the result of participants' interests to influence the flow and content of the workshop. For instance, to present private interests as formal knowledge (Mosse, 1994). In the case of extensive sheep farming in Huesca, Spain, collapse of the farming system seems pending, which may stimulate the expression of private as well as public interests to preserve the current system. The perception that the farming system has reached already certain thresholds could be a legitimate reason to avoid a discussion about where thresholds would lie exactly. The flexibility of the methodology allowed compensating the lack of individual input on critical threshold assessment by letting participants assess some other parts of the workshop individually. When discussing alternative systems, participants also expressed the need for a plenary discussion. Again, a pending collapse of the farming system may explain the need for immediate action, and thus not allowing for opportunities where time-consuming differences in opinion could arise. Another explanation could be that individual assessments were seen as dull, administrative tasks, resulting in reduced engagement and influence of certain stakeholder groups. Having plenary instead of individual input however also reduced the chance of having radical different ideas on alternative systems.

#### 4.2.4. *Adaptations or transformations?*

By focusing on only a few system *function indicators* and *resilience attributes*, the likelihood of proposing alternative systems that integrate for instance new goals is reduced: importance of *function indicators* and *resilience attributes* in the current system may need to be re-evaluated in the light of possible alternative systems. In that sense, the followed methodology is to a certain extent path-dependent. This coincides with path dependency of social-ecological systems in general where actors have stakes and often change needs to be realized based on the resources that have been built up in the system so far. In the presented case study, alternative system goals shifted somewhat, but were largely emphasizing differences among goals of lowland and highland farming. Also in applications in eight other EU farming systems, alternative systems proposed were adaptations rather than transformations. Only in an application where a desk study was performed (because of the Covid-19 situation) and main input was from experts, more radical transformations were proposed (Paas et al., 2020). Making farming system actors think about future change is indeed acknowledged as challenging (Meuwissen et al., 2020), but much needed in transition processes (Quist and Vergragt, 2006). As alternative to stakeholder participation, some foresight studies depend on expert opinions (e.g. Boland et al., 2013) or a literature study (e.g Figueiredo Junior et al., 2017). Although informative, these alternatives do not create a sense of ownership and engagement of local actors. Inviting radical thinkers from outside the system in a complementary workshop could help to challenge current mental models and to expose farming system actors to more radical ideas (Enfors-Kautsky et al., 2018; Westley et al., 2015). Another way to break free from established ways of thinking is to reframe the challenge (Enfors-Kautsky et al., 2018). For instance, by approaching it predominantly from an environmental perspective, a perspective that was not extensively discussed in the context of the workshop in the presented case study.

#### 4.2.5. *Representing the farming system*

The representation of the farming system in the framework of Kinzig et al. (2006) gives a quick overview of important interactions for a system in decline. It should be noted, however, that getting an adequate system representation is always work in progress (Walker and Salt, 2012) and complementary methods are probably needed. For instance, the framework of Kinzig et al. (2006) does not provide a complete overview on possibilities to avoid or reverse a decline in system performance, based on knowledge of balancing and reinforcing processes in the system. The development of a causal loop diagram provides more insight on where these processes can be expected but is less intuitive and more complicated to interpret. Still, a causal loop diagram could help to qualitatively assess the impact of specific strategies. Further integration of causal loop diagrams and scenarios in system dynamics models could lead to new knowledge on how global or EU scenarios play out at farming system level (Herrera and Kopainsky, 2020).

## 5. Conclusions

The methodology presented in this paper leads researchers in six steps to a multi-dimensional understanding of future sustainability and resilience of a farming system. Taking the current system as point of reference, the identification of interacting critical thresholds and assessing in a forecasting exercise the impact of exceeding these can explain how system sustainability and resilience can quickly decline (Step 1–3). Consequently, participants, being aware of this, are stimulated to think about alternative systems and their performance with regard to sustainability and resilience (Step 4). The alternative systems serve well as a point of reference in a back-casting exercise to identify the strategies that are needed to arrive at those alternative systems (Step 5). Although the workshop is originally designed to take five hours, taking more time for the workshop is advised as it will further improve understanding on the role of different strategies, actors and resources. Considering both feedback mechanisms (combining results from Step 1–5) and compatibility of alternative systems with Eur-Agri-SSPs (Step 6) provides a means of triangulation that allows for better understanding of strengths and weaknesses of the farming system, for instance with regard to the complementarity of sustainability and resilience of a system. Potential for decline (Step 1–3) and improvement (Step 4–6), simultaneously for sustainability and resilience, have been made clearly visible in the case study on the extensive sheep farming system that is included in this paper. Overall, the methodology can be regarded as relatively quick, interactive, flexible and interdisciplinary, enabling stakeholders to think and talk about the future sustainability and resilience of their system, paving the way for further discussions and also quantitative methods that can assess, ex-ante, the impact of strategies and scenarios.

## CRediT authorship contribution statement

**Wim Paas:** Conceptualization, Methodology, Software, Validation, Formal analysis, Writing – original draft, Writing - review & editing, Visualization. **Carolina San Martín:** Investigation, Data curation, Validation, Formal analysis, Writing – original draft, Writing - review & editing, Visualization. **Bárbara Soriano:** Investigation, Validation, Formal analysis, Writing - review & editing, Supervision, Project administration. **Martin K. van Ittersum:** Conceptualization, Writing - review & editing, Supervision. **Miranda P.M. Meuwissen:** Conceptualization, Writing - review & editing, Supervision, Funding acquisition. **Pytrik Reidsma:** Conceptualization, Methodology, Validation, Writing - review & editing, Supervision, Project administration, Funding acquisition.

## 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.

## Acknowledgements

We acknowledge the SURE-Farm Horizon 2020 project (Grant Agreement No 727520) for funding this study. We are thankful to all workshop participants, whose input was essential for this study. We are grateful for assistance from Isabel Bardaji, Alberto Garrido, José María Sumpsi and Daniele Bertolozzi-Caredio in the workshop. We thank two anonymous reviewers and colleagues in the Plant Production Systems Group of Wageningen University for providing constructive feedback on earlier versions of the manuscript.

## Appendix A. Concepts used in this study

**Table A1**
Used concepts and their explanations and main references. Adapted from Paas et al. (2021).

| Concept | Explanation | References |
|---|---|---|
| Sustainability | An adequate performance of all system functions across the environmental, economic and social domain. Obviously adequate is normative and depends on environmental thresholds and societal constraints and objectives. | See e.g. König et al. (2013); Morris et al. (2011) |
| Resilience capacities | Robustness, adaptability and transformability potential of systems in the face of shocks and stresses. The explanation of the resilience capacities follows below and is influenced by the mentioned sources. | Anderies et al. (2013); Folke et al. (2010); Meuwissen et al. (2019); Walker et al. (2004) |
| Robustness | Robustness is the capacity to resist to and endure shocks and stresses. | |
| Adaptability | Adaptability is the capacity to actively respond to shock and stresses without changing farming system structures and feedback mechanisms | |
| Transformability | Transformability is the capacity of a system to reorganize its structure and feedback mechanisms in response to shocks and stresses. | |
| Specific resilience | Resilience specified with regard to answering the questions "resilience of what, to what and for what purpose?" | Carpenter et al. (2001); Quinlan et al. (2016) |
| General resilience | General resilience is related to a system's robustness, adaptability and transformability, regardless the type of challenge or shock, including the unknown, uncertainty and surprise. | Resilience Alliance (2010), Walker and Salt (2012), Meuwissen et al. (2019) |
| Farming system | The basis of a farming systems consists of farms producing the main products of interest in a regional context. Farming system actors included in the farming systems are the producers of main products and other actors that mutually influence one another. In the context of resilience, the farming system relates to the question "Resilience of what?" | Meuwissen et al. (2019) |
| *Challenges* | Shocks or stresses that constrain farming system functioning. In the context of resilience, challenges relate to the question "Resilience to what?". | Meuwissen et al. (2019) |
| *Functions* | Delivery of public and private goods from the farming system to society (categorized according to the domain they belong to): production of food (economic), bio-based resources (economic), economic viability (economic), quality of life (social), maintenance of natural resources (environmental), biodiversity & habitat (environmental), attractiveness of the area (social), and animal health & welfare (environmental). | Meuwissen et al. (2019) |
| *Function indicators* | Indicators that represent farming system functions in the absence of a unique metric for these functions. Indicators with high allocated importance are assumed to represent the identity of the farming system. | Paas et al. (2021), Meuwissen et al. (2019) |
| *Resilience attributes* | Specific system characteristics that are supposedly contributing to general resilience of farming systems. For the resilience attributes that are treated in this study, see also Table A2. | Cabell and Oelofse (2012), Meuwissen et al. (2019) |
| Critical thresholds | Levels at which function indicators, resilience attributes or challenges are expected to cause large and permanent system change. | |
| Adapted from Kinzig et al. (2006), Biggs et al. (2018). | Enabling conditions | Conditions around the farming system that enable the maintenance of the current system or the realization of alternative systems in the future. |
| This study | Interacting thresholds | Critical thresholds, when exceeded, leading to the exceedance of another critical threshold. |
| Kinzig et al. (2006) | Current strategies | Strategies implemented to counteract impact of current shocks and stresses on the farming system (indicators). |
| Paas et al. (2021), Meuwissen et al. (2019) | Future strategies | Strategies to maintain the current system in the future or to realize alternative systems in the future. |

**Table A2**
Resilience attribute definitions and implications. Source: Paas et al. (2021) based on (Cabell and Oelofse, 2012) and (Meuwissen et al., 2019).

| Resilience attribute | Definition | Implications | Explanation statement |
|---|---|---|---|
| Reasonably profitable | Persons and organizations in the farming system are able to make a livelihood and save money without relying on subsidies or secondary employment | Being reasonably profitable allows participants in the system to invest in the future; this adds buffering capacity, flexibility, and builds wealth that can be tapped into following release | Farmers and farm workers earn a livable wage while not depending heavily on subsidies |
| Production coupled with local and natural capital | The system functions as much as possible within the means of the bio-regionally available natural resource base and ecosystem services | Responsible use of local resources encourages a system to live within its means; this creates an agroecosystem that recycles waste, relies on healthy soil, and conserves water | Soil fertility, water resources and existing nature are maintained well |
| Functional diversity | Functional diversity is the variety of (ecosystem) services that components provide to the system | Diversity buffers against perturbations (insurance) and provides seeds of renewal following disturbance | There is a high variety of inputs, outputs, income sources and markets |
| Response diversity | Response diversity is the range of responses of these components to environmental change | Diversity buffers against perturbations (insurance) and provides seeds of renewal following disturbance | There is a high diversity of risk management strategies , e.g. different pest controls, weather insurance, flexible payment arrangements |
| Exposed to disturbance | The system is exposed to discrete, low-level events that cause disruptions without pushing the system beyond a critical threshold | Such frequent, small-scale disturbances can increase system resilience and adaptability in the long term by promoting natural selection and novel configurations during the phase of renewal; described as "creative destruction" | The amount of year to year economic, environmental, social or institutional disturbance is small (well dosed) in order to timely adapt to a changing environment |
| Spatial and temporal heterogeneity of farm types | Patchiness across the landscape and changes through time | Like diversity, spatial heterogeneity provides seeds of renewal following disturbance | There is a high diversity of farm types with regard to economic size, intensity, orientation and degree of specialization |
| Optimally redundant farms | Critical components and relationships within the system are duplicated in case of failure | Redundancy may decrease a system's efficiency, but it gives the system multiple back-ups, increases buffering capacity, and provides seeds of renewal following disturbance | Farmers can stop without endangering continuation of the farming system and new farmers can enter the farming system easily |
| Supports rural life | The activities in the farming system attract and maintain a healthy and adequate workforce, including young, intermediate and older people | A healthy workforce that includes multiple generations will ensure continuation of activities and facilities in the area, and the timely transfer of knowledge | Rural life is supported by the presence of people from all generations, and also supported by enough facilities in the nearby area (e.g. supermarkets, hospital, shops) |
| Socially self-organized | The social components of the agroecosystem are able to form their own configuration based on their needs and desires | Systems that exhibit greater level of self-organization need fewer feedbacks introduced by managers and have greater intrinsic adaptive capacity | Farmers are able to organize themselves into networks and institutions such as co-ops, community associations, advisory networks and clusters with the processing industry |
| Appropriately connected with actors outside the farming system | The social components of the agroecosystem are able to form ties with actors outside their farming system | In case self-organization fails, signals can be send to actors that indirectly influence the farming system | Farmers and other actors in the farming system are able to reach out to policy makers, suppliers and markets that operate at the national and EU level |
| Legislation coupled with local and natural capital | Regulations are developed to let[‡] the system function as much as possible within the means of the bio-regionally available natural resource base and ecosystem services | Responsible use of local resources encourages a system to live within its means; this creates an agroecosystem that recycles waste, relies on healthy soil, and conserves water | Norms, legislation and regulatory frameworks are well adapted to the local conditions |
| Infrastructure for innovation | Existing infrastructure facilitates diffusion of knowledge and adoption of cutting-edge technologies (e.g. digital) | Through timely adoption of new knowledge and technologies, a farming system can better navigate in a changing environment | Existing infrastructure facilitates knowledge and adoption of cutting-edge technologies (e.g. digital) |
| Diverse policies | Various policy instruments stimulate different mechanisms that improve different resilience capacities | Policies addressing all three resilience capacities avoid situations in which farming systems are permanently locked in a robust but unsustainable situation. Or situations in which adapting and transforming systems are increasingly vulnerable | Policies stimulate all three capacities of resilience, i.e. robustness, adaptability, transformability |

## Appendices B–E. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecolind.2021.108236.

## References


Allison, H.E., Hobbs, R.J., 2004. Resilience, adaptive capacity, and the "lock-in trap" of the Western Australian agricultural region. Ecol. Soc. 9, 3. https://doi.org/10.5751/ES-00641-090103.

Anderies, J.M., Folke, C., Walker, B., Ostrom, E., 2013. Aligning key concepts for global change policy: Robustness, resilience, and sustainability. Ecol. Soc. 18, 8. https://doi.org/10.5751/ES-05178-180208.

Andersen, E., Elbersen, B., Godeschalk, F., Verhoog, D., 2007. Farm management indicators and farm typologies as a basis for assessments in a changing policy environment. J. Environ. Manage. 82 (3), 353–362.

Becking, J., Soriano, B., Bardaji, I., 2019. FoPIA-SURE-Farm Case-study Report Spain, in: Paas, W., Accatino, F., Antonioli, F., Appel, F., Bardaji, I., Coopmans, I., Courtney, P., Gavrilescu, C., Heinrich, F., Krupin, V., Manevska-Tasevska, G., Neumeister, D., Peneva, M., Rommel, J., Severini, S., Soriano, B., Tudor, M., Urquhart, J., Wauters, E., Zawalinska, K., Meuwissen, M., Reidsma, P. (Eds.), D5.2 Participatory Impact Assessment of Sustainability and Resilience of EU Farming Systems. Sustainable and Resilient EU Farming Systems (SURE-Farm) Project Report.

Bernués, A., Olaizola, A., 2012. La ganadería en los Pirineos: Evolución, condicionantes y oportunidades. In: Lasagabaster, I. (Ed.), Los Pirineos: Geografía. Universidad del País Vasco, Turismo, Agricultura, Cooperación Transfronteriza y Derecho, pp. 29–67.

Bernués, A., Riedel, J.L., Asensio, M.A., Blanco, M., Sanz, A., Revilla, R., Casasús, I., 2005. An integrated approach to studying the role of grazing livestock systems in the conservation of rangelands in a protected natural park (Sierra de Guara, Spain). Livest. Prod. Sci. 96 (1), 75–85. https://doi.org/10.1016/j.livprodsci.2005.05.023.

Bernués, A., Riedel, J.L., Casasús, I., Olaizola, A., 2006. The conservation of natural resources as an extrinsic quality attribute of lamb in Mediterranean Areas. In: Ramalhi Ribeiro, J., Horta, A., Mosconi, C., Rosati, A. (Eds.), Animal Products from the Mediterranean Area, EAAP Publication 119. Wageningen Academic Publishers, pp. 73–82.

Bernués, A., Ruiz, R., Olaizola, A., Villalba, D., Casasús, I., 2011. Sustainability of pasture-based livestock farming systems in the European Mediterranean context: Synergies and trade-offs. Livest. Sci. 139 (1-2), 44–57. https://doi.org/10.1016/j.livsci.2011.03.018.

Bertolozzi-Caredio, D., Garrido, A., Soriano, B., Bardaji, I., 2021. Implications of alternative farm management patterns to promote resilience in extensive sheep farming. A Spanish case study. J. Rural Stud. 86, 633–644. https://doi.org/10.1016/J.JRURSTUD.2021.08.007.

Biggs, R., Peterson, G.D., Rocha, J.C., 2018. The Regime Shifts Database: a framework for analyzing regime shifts in social-ecological systems. Ecol. Soc. 23, 9. https://doi.org/10.5751/ES-10264-230309.

Boland, M.J., Rae, A.N., Vereijken, J.M., Meuwissen, M.P.M., Fischer, A.R.H., van Boekel, M.A.J.S., Rutherfurd, S.M., Gruppen, H., Moughan, P.J., Hendriks, W.H., 2013. The future supply of animal-derived protein for human consumption. Trends Food Sci. Technol. 29 (1), 62–73. https://doi.org/10.1016/j.tifs.2012.07.002.

Bosque, M.A., Navarro, V.P., 2002. El proceso de desertización demográfica de la montaña pirenaica en el largo plazo: Aragón. Ager Rev. Estud. sobre despoblación y Desarro. Rural = J. depopulation Rural Dev. Stud. 2, 101–138.

Cabell, J.F., Oelofse, M., 2012. An Indicator Framework for Assessing Agroecosystem Resilience. Ecol. Soc. 17, 18. https://doi.org/10.5751/ES-04666-170118.

Callo-Concha, D., Ewert, F., 2014. Using the Concepts of Resilience, Vulnerability and Adaptability for the Assessment and Analysis of Agricultural Systems. Chang. Adapt. Socio-Ecological Syst. 1, 1–11. https://doi.org/10.2478/cass-2014-0001.

Carpenter, S., Walker, B., Anderies, J.M., Abel, N., 2001. From Metaphor to Measurement: Resilience of What to What? Ecosystems 4 (8), 765–781. https://doi.org/10.1007/s10021-001-0045-9.

Casasús, I., Bernués, A., Sanz, A., Villalba, D., Riedel, J.L., Revilla, R., 2007. Vegetation dynamics in Mediterranean forest pastures as affected by beef cattle grazing. Agric. Ecosyst. Environ. 121 (4), 365–370. https://doi.org/10.1016/j.agee.2006.11.012.

Corcoran, K., 2003. Marketing red meat in the European Union: extending the options, Final Report of project FAIR (SME) FA-S2-CT98-9093 (CRAFT programme).

Figueiredo Junior, H.S.d., Meuwissen, M.P.M., van der Lans, I.A., Oude Lansink, A.G.J.M., Jadhao, S.B., 2017. Beyond upgrading typologies – In search of a better deal for honey value chains in Brazil. PLoS One 12 (7), e0181391. https://doi.org/10.1371/journal.pone.018139110.1371.

de Rancourt, M., Fois, N., Lavín, M.P., Tchakérian, E., Vallerand, F., 2006. Mediterranean sheep and goats production: An uncertain future. Small Rumin. Res. 62 (3), 167–179. https://doi.org/10.1016/j.smallrumres.2005.08.012.

Delmotte, S., Lopez-Ridaura, S., Barbier, J.M., Wery, J., 2013. Prospective and participatory integrated assessment of agricultural systems from farm to regional scales: Comparison of three modeling approaches. J. Environ. Manage. 129, 493–502. https://doi.org/10.1016/j.jenvman.2013.08.001.

DG-AGRI, 2017. Agricultural and farm income. https://ec.europa.eu/agriculture/sites/agriculture/files/statistics/facts-figures/agricultural-farm-income.pdf.

Dreborg, K.H., 1996. Essence of backcasting. Futures 28 (9), 813–828. https://doi.org/10.1016/S0016-3287(96)00044-4.

Enfors-Kautsky, E., Järnberg, L., Quinlan, A., Ryan, P., 2018. Wayfinder: a resilience guide for navigating towards sustainable futures [WWW Document]. GRAID Program. Stock. Resil, Centre https://wayfinder.earth/ (accessed 6.1.21).

Eurofound, 2019. Is rural Europe being left behind? European Quality of Life Survey 2016. Publications Office of the European Union, Luxembourg.

Folke, C., Carpenter, S.R., Walker, B., Scheffer, M., Chapin, T., Rockström, J., 2010. Resilience thinking: integrating resilience, adaptability and transformability. Ecol. Soc. 15 (4), 20.

García-Martínez, A., Olaizola, A., Bernués, A., 2009. Trajectories of evolution and drivers of change in European mountain cattle farming systems. Animal 3 (1), 152–165. https://doi.org/10.1017/S1751731108003297.

Geoghegan, Jacqueline, Wainger, Lisa A., Bockstael, Nancy E., 1997. Spatial landscape indices in a hedonic framework: An ecological economics analysis using GIS. Ecol. Econ. 23 (3), 251–264. https://doi.org/10.1016/S0921-8009(97)00583-1.

Gobierno de Aragón, 2019. Datos estadísticos sobre ganadería en Aragón: efectivos ganaderos, distribución de ganadería, movimiento comercial pecuario, producciones ganaderas. https://www.aragon.es/-/estadisticas-ganaderas.

Gobierno de Aragón, 2016. El ovino y el caprino en Aragón. Evolución en los últimos 20 años (1996-2016). https://citarea.cita-aragon.es/citarea/bitstream/10532/3542/1/Castellano_estudio.pdf.

Hernández-Mora, N., Gil, M., Garrido, A., Rodríguez-Casado, R., 2012. La sequía 2005–2008 en la cuenca del Ebro: vulnerabilidad, impactos y medidas de gestión. UPM-CEIGRAM-Madrid.

Herrera, H., 2017. From Metaphor to Practice: Operationalizing the Analysis of Resilience Using System Dynamics Modelling. Syst. Res. Behav. Sci. 34, 444–462. https://doi.org/10.1002/sres.2468.

Herrera, Hugo, Kopainsky, Birgit, 2020. Using system dynamics to support a participatory assessment of resilience. Environ. Syst. Decis. 40 (3), 342–355. https://doi.org/10.1007/s10669-020-09760-5.

Kharrazi, Ali, Savaget, Paulo, Kudo, Shogo, 2019. In: Encyclopedia of Sustainability in Higher Education. Springer International Publishing, Cham, pp. 1–4. https://doi.org/10.1007/978-3-319-63951-2_92-1.

Kinzig, A.P., Ryan, P., Etienne, M., Allison, H., Elmqvist, T., Walker, B.H., 2006. Resilience and regime shifts: Assessing cascading effects. Ecol. Soc. 11, 20. https://doi.org/10.5751/ES-01678-110120.

König, H.J., Uthes, S., Schuler, J., Zhen, L., Purushothaman, S., Suarma, U., Sghaier, M., Makokha, S., Helming, K., Sieber, S., Chen, L., Brouwer, F., Morris, J., Wiggering, H., 2013. Regional impact assessment of land use scenarios in developing countries using the FoPIA approach: Findings from five case studies. J. Environ. Manage. 127, S56–S64. https://doi.org/10.1016/j.jenvman.2012.10.021.

Lasanta-Martínez, Teodoro, Vicente-Serrano, Sergio M., Cuadrat-Prats, José Ma, 2005. Mountain Mediterranean landscape evolution caused by the abandonment of traditional primary activities: A study of the Spanish Central Pyrenees. Appl. Geogr. 25 (1), 47–65. https://doi.org/10.1016/j.apgeog.2004.11.001.

MAPA, 2017. Estudios de costes y rentas de explotaciones ganaderas (ECREA) [WWW Document]. URL https://www.mapa.gob.es/es/ministerio/servicios/analisis-y-prospectiva/ganadoovinocarne_tcm30-508573.pdf.

MAPA, 2019a. Encuestas de efectivos de ganado ovino y caprino [WWW Document]. URL https://www.mapa.gob.es/es/estadistica/temas/estadisticas-agrarias/resultados_definitivos_nov2019_ovino-caprino_tcm30-526727.pdf.

MAPA, 2019b. Anuario de estadística [WWW Document]. URL https://www.mapa.gob.es/estadistica/pags/anuario/2019/CAPITULOSPDF/CAPITULO03/pdfc03_3.pdf.

MAPA, 2019c. Red contable agraria nacional (RECAN) [WWW Document]. URL https://www.mapa.gob.es/es/estadistica/temas/estadisticas-agrarias/economia/red-contable-recan/ (accessed 6.5.19).

MAPA, 2020. El sector ovino y caprino en cifras. Principales indicadores económicos [WWW Document]. URL https://www.mapa.gob.es/es/ganaderia/temas/produccion-y-mercados-ganaderos/indicadoreseconomicosdelsectorovinoycaprino_carne_tcm30-5114962019_tcm30-511496.pdf.

Marchese, D., Reynolds, E., Bates, M.E., Morgan, H., Clark, S.S., Linkov, I., 2018. Resilience and sustainability: Similarities and differences in environmental management applications. Sci. Total Environ. 613–614, 1275–1283. https://doi.org/10.1016/J.SCITOTENV.2017.09.086.

Martin-Collado, D., Díaz Martín, C., Serrano, M., Carabaño, M., Ramón, M., Zanoli, R., 2019. Sheep dairy and meat products: from urban consumers' perspective to industry innovations. Options Méditerranéennes 123, 277–281.

Mathijs, Erik, Wauters, Erwin, 2020. Making farming systems truly resilient. Eurochoices 19 (2), 72–76. https://doi.org/10.1111/euch.v19.210.1111/1746-692X.12287.

Meuwissen, Miranda P.M., Feindt, Peter H., Midmore, Peter, Wauters, Erwin, Finger, Robert, Appel, Franziska, Spiegel, Alisa, Mathijs, Erik, Termeer, Katrien J.A.M., Balmann, Alfons, Mey, Yann, Reidsma, Pytrik, 2020. The struggle of farming systems in Europe: looking for explanations through the lens of resilience. Eurochoices 19 (2), 4–11. https://doi.org/10.1111/euch.v19.210.1111/1746-692X.12278.

Meuwissen, M.P.M., Feindt, P.H., Slijper, T., Spiegel, A., Finger, R., de Mey, Y., Paas, W., Termeer, K.J.A.M., Poortvliet, P.M., Peneva, M., Urquhart, J., Vigani, M., Black, J.E., Nicholas-Davies, P., Maye, D., Appel, F., Heinrich, F., Balmann, A., Bijttebier, J., Coopmans, I., Wauters, E., Mathijs, E., Hansson, H., Lagerkvist, C.J., Rommel, J., Manevska-Tasevska, G., Accatino, F., Pineau, C., Soriano, B., Bardaji, I., Severini, S., Senni, S., Zinnanti, C., Gavrilescu, C., Bruma, I.S., Dobay, K.M., Matei, D., Tanasa, L., Voicilas, D.M., Zawalińska, K., Gradziuk, P., Krupin, V., Martikainen, A., Herrera, H., Reidsma, P., 2021. Impact of Covid-19 on farming systems in Europe through the lens of resilience thinking. Agric. Syst. 191, 103152. https://doi.org/10.1016/j.agsy.2021.103152.

Meuwissen, Miranda P.M., Feindt, Peter H., Spiegel, Alisa, Termeer, Catrien J.A.M., Mathijs, Erik, Mey, Yann de, Finger, Robert, Balmann, Alfons, Wauters, Erwin, Urquhart, Julie, Vigani, Mauro, Zawalińska, Katarzyna, Herrera, Hugo, Nicholas-Davies, Phillipa, Hansson, Helena, Paas, Wim, Slijper, Thomas, Coopmans, Isabeau, Vroege, Willemijn, Ciechomska, Anna, Accatino, Francesco, Kopainsky, Birgit, Poortvliet, P. Marijn, Candel, Jeroen J.L., Maye, Damian, Severini, Simone, Senni, Saverio, Soriano, Bárbara, Lagerkvist, Carl-Johan, Peneva, Mariya, Gavrilescu, Camelia, Reidsma, Pytrik, 2019. A framework to assess the resilience of farming systems. Agric. Syst. 176, 102656. https://doi.org/10.1016/j.agsy.2019.102656.

Milán, M.J., Arnalte, E., Caja, G., 2003. Economic profitability and typology of Ripollesa breed sheep farms in Spain. Small Rumin. Res. 49 (1), 97–105. https://doi.org/10.1016/S0921-4488(03)00058-0.

Mitter, Hermine, Techen, Anja-K., Sinabell, Franz, Helming, Katharina, Schmid, Erwin, Bodirsky, Benjamin L., Holman, Ian, Kok, Kasper, Lehtonen, Heikki, Leip, Adrian, Le Mouël, Chantal, Mathijs, Erik, Mehdi, Bano, Mittenzwei, Klaus, Mora, Olivier, Øistad, Knut, Øygarden, Lillian, Priess, Jörg A., Reidsma, Pytrik, Schaldach, Rüdiger, Schönhart, Martin, 2020. Shared Socio-economic Pathways for European agriculture and food systems: The Eur-Agri-SSPs. Glob. Environ. Chang. 65, 102159. https://doi.org/10.1016/j.gloenvcha.2020.102159.

Mitter, Hermine, Techen, Anja-K., Sinabell, Franz, Helming, Katharina, Kok, Kasper, Priess, Jörg A., Schmid, Erwin, Bodirsky, Benjamin L., Holman, Ian, Lehtonen, Heikki, Leip, Adrian, Le Mouël, Chantal, Mathijs, Erik, Mehdi, Bano, Michetti, Melania, Mittenzwei, Klaus, Mora, Olivier, Øygarden, Lillian, Reidsma, Pytrik, Schaldach, Rüdiger, Schönhart, Martin, 2019. A protocol to develop Shared Socio-economic Pathways for European agriculture. J. Environ. Manage. 252, 109701. https://doi.org/10.1016/j.jenvman.2019.109701.

Morris, J.B., Tassone, V., de Groot, R., Camilleri, M., Moncada, S., 2011. A framework for participatory impact assessment: Involving stakeholders in European policy making, A case study of land use change in Malta. Ecol. Soc. 16, 12.

Mosse, D., 1994. Authority, Gender and Knowledge: Theoretical Reflections on the Practice of Participatory Rural Appraisal. Dev. Change 25. https://doi.org/10.1111/j.1467-7660.1994.tb00524.x.

Nemec, K.T., Chan, J., Hoffman, C., Spanbauer, T.L., Hamm, J.A., Allen, C.R., Hefley, T., Pan, D., Shrestha, P., 2014. Assessing resilience in stressed watersheds. Ecol. Soc. 19, 34. https://doi.org/10.5751/ES-06156-190134.

Nera, E., Paas, W., Reidsma, P., Paolini, G., Antonioli, F., Severini, S., 2020. Assessing the Resilience and Sustainability of a Hazelnut Farming System in Central Italy with a Participatory Approach. Sustainability 12, 343. https://doi.org/10.3390/su12010343.

Ornai, Alon, Ne'eman, Gidi, Keasar, Tamar, 2020. Management of forest fire buffer zones: Implications for flowering plants and bees. For. Ecol. Manage. 473, 118310. https://doi.org/10.1016/j.foreco.2020.118310.

Paas, W., Accatino, F., Antonioli, F., Appel, F., Bardaji, I., Coopmans, I., Courtney, P., Gavrilescu, C., Heinrich, F., Krupin, V., Manevska-Tasevska, G., Neumeister, D., Peneva, M., Rommel, J., Severini, S., Soriano, B., Tudor, M., Urquhart, J., Wauters, E., Zawalinska, K., Meuwissen, M., Reidsma, P., 2019. D5.2 Participatory impact assessment of sustainability and resilience of EU farming systems. Sustainable and resilient EU farming systems (SureFarm) project report, EU Horizon 2020 Grant Agreement No. 727520.

Paas, W., Accatino, F., Appel, F., Bijttebier, J., Black, J., Gavrilescu, C., Krupin, V., Manevska-Tasevska, G., Ollendorf, F., Peneva, M., Rommel, J., San Martín, C., Severini, S., Soriano, B., Valchovska, S., Vigani, M., Wauters, E., Zawalińska, K., Zinnanti, C., Meuwissen, M., Reidsma, P., 2020. FoPIA-SURE-Farm 2, in: Accatino, F., Paas, W., Herrera, H., Appel, F., Pinsard, C., Yong, S., Schutz, L., Kopainsky, B., Bańkowska, K., Bijttebier, J., Black, J., Gavrilescu, C., Krupin, V., Manevska-Tasevska, G., Ollendorf, F., Peneva, M., Rommel, J., San Martín, C., Severini, S., Soriano, B., Valchovska, S., Vigani, M., Wauters, E., Zawalińska, K., Zinnanti, C., Meuwissen, M., Reidsma, P. (Eds.), D5.5 Impacts of Future Scenarios on the Resilience of Farming Systems across the EU Assessed with Quantitative and Qualitative Methods. Sustainable and resilient EU farming systems (SURE-Farm) project report, EU Horizon 2020 Grant Agreement No. 727520.

Paas, W., Coopmans, I., Severini, S., van Ittersum, M., Meuwissen, M., Reidsma, P., 2021. Participatory assessment of sustainability and resilience of three specialized farming systems. Ecol. Soc. 26, 2. https://doi.org/10.5751/ES-12200-260202.

Pardos, L., Maza, M.T., Fantova, E., 2007. Influencia de la prima fija en los resultados técnicos y económicos de explotaciones ovinas de carne en Aragón. ITEA 28, 291–293.

Pardos, L., Maza, M.T., Fantova, E., Sepúlveda, W., 2008. The diversity of sheep production systems in Aragón (Spain): Characterisation and typification of meat sheep farms. Spanish J. Agric. Res. 6, 497–507. https://doi.org/10.5424/sjar/2008064-344.

Peco, B., Navarro, E., Carmona, C.P., Medina, N.G., Marques, M.J., 2017. Effects of grazing abandonment on soil multifunctionality: The role of plant functional traits. Agric. Ecosyst. Environ. 249, 215–225. https://doi.org/10.1016/j.agee.2017.08.013.

Quinlan, Allyson E., Berbés-Blázquez, Marta, Haider, L. Jamila, Peterson, Garry D., Allen, Craig, 2016. Measuring and assessing resilience: broadening understanding through multiple disciplinary perspectives. J. Appl. Ecol. 53 (3), 677–687. https://doi.org/10.1111/1365-2664.12550.

Quist, Jaco, Vergragt, Philip, 2006. Past and future of backcasting: The shift to stakeholder participation and a proposal for a methodological framework. Futures 38 (9), 1027–1045. https://doi.org/10.1016/j.futures.2006.02.010.

Rabbinge, R., van Diepen, C.A., 2000. Changes in agriculture and land use in Europe. Eur. J. Agron. 13 (2-3), 85–99.

Reidsma, P., Bakker, M.M., Kanellopoulos, A., Alam, S.J., Paas, W., Kros, J., de Vries, W., 2015. Sustainable agricultural development in a rural area in the Netherlands? Assessing impacts of climate and socio-economic change at farm and landscape level. Agric. Syst. 141, 160–173. https://doi.org/10.1016/j.agsy.2015.10.009.

Reidsma, Pytrik, Meuwissen, Miranda, Accatino, Francesco, Appel, Franziska, Bardaji, Isabel, Coopmans, Isabeau, Gavrilescu, Camelia, Heinrich, Florian, Krupin, Vitaliy, Manevska-Tasevska, Gordana, Peneva, Mariya, Rommel, Jens, Severini, Simone, Soriano, Bárbara, Urquhart, Julie, Zawalińska, Katarzyna, Paas, Wim, 2020. How do stakeholders perceive the sustainability and resilience of EU farming systems? Eurochoices 19 (2), 18–27. https://doi.org/10.1111/euch.v19.210.1111/1746-692X.12280.

Reidsma, P., Paas, W., Spiegel, A., Meuwissen, M., 2019. Guidelines for the Framework of Participatory Impact Assessment of SUstainable and REsilient EU FARMing systems (FoPIA-Surefarm), in: Paas, W., Accatino, F., Antonioli, F., Appel, F., Bardaji, I., Coopmans, I., Courtney, P., Gavrilescu, C., Heinrich, F., Krupin, V., Manevska-Tasevska, G., Neumeister, D., Peneva, M., Rommel, J., Severini, S., Soriano, B., Tudor, M., Urquhart, J., Wauters, E., Zawalinska, K., Meuwissen, M., Reidsma, P. (Eds.), D5.2 Participatory Impact Assessment of Sustainability and Resilience of EU Farming Systems. Sustainable and resilient EU farming systems (SURE-Farm) project report, EU Horizon 2020 Grant Agreement No. 727520.

Resilience Alliance, 2010. Assessing resilience in social-ecological systems: Workbook for practitioners. Version 2.

Riedel, J.L., Casasús, I., Bernués, A., 2007. Sheep farming intensification and utilization of natural resources in a Mediterranean pastoral agro-ecosystem. Livest. Sci. 111 (1-2), 153–163. https://doi.org/10.1016/j.livsci.2006.12.013.

Rodríguez-Ortega, T., Oteros-Rozas, E., Ripoll-Bosch, R., Tichit, M., Martín-López, B., Bernués, A., 2014. Applying the ecosystem services framework to pasture-based livestock farming systems in Europe. Animal 8 (8), 1361–1372. https://doi.org/10.1017/S1751731114000421.

Ruiz-Mirazo, Jabier, Robles, Ana Belén, 2012. Impact of targeted sheep grazing on herbage and holm oak saplings in a silvopastoral wildfire prevention system in south-eastern Spain. Agrofor. Syst. 86 (3), 477–491. https://doi.org/10.1007/s10457-012-9510-z.

Shucksmith, Mark, Cameron, Stuart, Merridew, Tanya, Pichler, Florian, 2009. Urban-Rural Differences in Quality of Life across the European Union. Reg. Stud. 43 (10), 1275–1289. https://doi.org/10.1080/00343400802378750.

Sieber, S., Amjath-Babu, T.S., Reidsma, P., Koenig, H., Piorr, A., Bezlepkina, I., Mueller, K., 2018. Sustainability impact assessment tools for land use policy advice: A comparative analysis of five research approaches. Land Use Policy 71, 75–85. https://doi.org/10.1016/j.landusepol.2017.11.042.

Silva, Vasco, Catry, Filipe X., Fernandes, Paulo M., Rego, Francisco C., Paes, Paula, Nunes, Leónia, Caperta, Ana D., Sérgio, Cecília, Bugalho, Miguel N., 2019. Effects of grazing on plant composition, conservation status and ecosystem services of Natura 2000 shrub-grassland habitat types. Biodivers. Conserv. 28 (5), 1205–1224. https://doi.org/10.1007/s10531-019-01718-7.

Soriano, B., Bardají, I., Bertolozzi, D., San Martín, C., Spiegel, A., Slijper, T., Meuwissen, M.P.M., Rommen, J., Hansson, H., Severini, S., Antonioli, F., Berry, R., Kahfagy, A., Urquhart, J., Harizanova-Bartos, H., Stoyonova, Z., Coopmans, I., Wauters, E., Bijttebier, J., Neumister, D., Accatino, F., Pinsard, C., Tudor, M.M., Gavrilescu, C., Luca, L., Izvoranu, A.M., Zawalińska, K., Jendrzejewski, B., Gradziuk, P., BAŃKOWSKA, K., Krupin, V., Ollendorf, F., Appel, F., Garrido, A., 2020. D2.6 Report on state and outlook for risk management in EU agriculture. Sustainable and resilient EU farming systems (SURE-Farm) project report, EU Horizon 2020 Grant Agreement No. 727520.

Strijker, Dirk, 2005. Marginal lands in Europe - Causes of decline. Basic Appl. Ecol. 6 (2), 99–106. https://doi.org/10.1016/j.baae.2005.01.001.

ten Berge, H.F.M., van Ittersum, M.K., Rossing, W.A.H., van de Ven, G.W.J., Schans, J., 2000. Farming options for The Netherlands explored by multi-objective modelling. Eur. J. Agron. 13 (2-3), 263–277. https://doi.org/10.1016/S1161-0301(00)00078-2.

Tendall, D.M., Joerin, J., Kopainsky, B., Edwards, P., Shreck, A., Le, Q.B., Kruetli, P., Grant, M., Six, J., 2015. Food system resilience: Defining the concept. Glob. Food Sec. 6, 17–23. https://doi.org/10.1016/j.gfs.2015.08.001.

Tilman, David, Cassman, Kenneth G., Matson, Pamela A., Naylor, Rosamond, Polasky, Stephen, 2002. Agricultural sustainability and intensive production practices. Nature 418 (6898), 671–677. https://doi.org/10.1038/nature01014.

Tittonell, Pablo, 2020. Assessing resilience and adaptability in agroecological transitions. Agric. Syst. 184, 102862. https://doi.org/10.1016/j.agsy.2020.102862.

Turner, Neil C., 2004. Sustainable production of crops and pastures under drought in a Mediterranean environment. Ann. Appl. Biol. 144 (2), 139–147.

Vaidya, Ashma, Mayer, Audrey L., 2014. Use of the participatory approach to develop sustainability assessments for natural resource management. Int. J. Sustain. Dev. World Ecol. 21 (4), 369–379. https://doi.org/10.1080/13504509.2013.868376.

van Ittersum, M.K., Rabbinge, R., van Latesteijn, H.C., 1998. Exploratory land use studies and their role in strategic policy making. Agric. Syst. 58 (3), 309–330.

Van Passel, Steven, Massetti, Emanuele, Mendelsohn, Robert, 2017. A Ricardian Analysis of the Impact of Climate Change on European Agriculture. Environ. Resour. Econ. 67 (4), 725–760. https://doi.org/10.1007/s10640-016-0001-y.

Vicente-Serrano, S., Lasanta-Martínez, Teodoro Cuadrat-Prats, J., 2000. Influencia de la ganadería en la evolución del riesgo de incendio en función de la vegetación en un área de montaña: el ejemplo del valle de Borau (Pirineo aragonés). Geographicalia 33–58. https://doi.org/10.26754/ojs_geoph/geoph.2000381382.

Walker, B., Carpenter, S., Anderies, J., Abel, N., Cumming, G., Janssen, M., Lebel, L., Norberg, J., Peterson, G.D., Pritchard, R., 2002. Resilience management in social-ecological systems: A working hypothesis for a participatory approach. Ecol. Soc. 6, 14.

Walker, B., Holling, C.S., Carpenter, S.R., Kinzig, A.P., 2004. Resilience, Adaptability and Transformability in Social–ecological Systems. Ecol. Soc. 9 (2), 5.

Walker, B., Salt, D., 2012. Resilience practice: Building capacity to absorb disturbance and maintain function. Island Press, Washington D.C., USA. https://doi.org/10.5822/978-1-61091-231-0.

Westley, F., Laban, S., Rose, C., McGowan, K., Robinson, K., Tjornbo, O., Tovey, M., 2015. Social Innovation Lab Guide.

Westley, Frances, Olsson, Per, Folke, Carl, Homer-Dixon, Thomas, Vredenburg, Harrie, Loorbach, Derk, Thompson, John, Nilsson, Måns, Lambin, Eric, Sendzimir, Jan, Banerjee, Banny, Galaz, Victor, van der Leeuw, Sander, 2011. Tipping toward sustainability: Emerging pathways of transformation. Ambio 40 (7), 762–780. https://doi.org/10.1007/s13280-011-0186-9.

Wittmayer, Julia M., Schäpke, Niko, 2014. Action, research and participation: roles of researchers in sustainability transitions. Sustain. Sci. 9 (4), 483–496. https://doi.org/10.1007/s11625-014-0258-4.