Project acronym: SURE-Farm
Project no.: 727520
Start date of project: June 2017
Duration: 4 years

D5.6 Impacts of improved strategies and policy options on the resilience of farming systems across the EU

Work performed by all partners (lead P1 WU)

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Due date	30/September/2020
Version/Date	Final version 30/September/2020
Work Package	WP5
Task	T5. 4
Task lead	WU
Dissemination level	Public

INDEX

This Project has received funds from the European Union’s Horizon 2020 research and innovation programme under Grant Agreement No. 727520

Please cite this deliverable as:

Reidsma, P., W. Paas, F. Accatino, F. Appel, J. Black, J. Bijttebier, C. Gavrilescu, B. Kopainsky, V. Krupin, G. Manevska Tasevska, M. Meuwissen, F. Ollendorf, M. Peneva, S. Senni, S. Severini, B. Soriano, J. Urquhart, M. Vigani, K. Zawalinska, C. Zinnanti, H. Herrera, 2020. D5.6 Impacts of improved strategies and policy options on the resilience of farming systems across the EU. Sustainable and resilient EU farming systems (SURE-Farm) project report, EU Horizon 2020 Grant Agreement No. 727520.

Abstract

The sustainability and resilience of EU farming systems are threatened. According to stakeholders in selected EU farming systems, many of these systems are close to critical thresholds regarding the challenges they face (e.g., droughts, price declines), functions they deliver (e.g., economic viability, biodiversity and habitat) and attributes required for resilience (e.g., social self-organization). Strategies are required that increase the sustainability and resilience of EU farming systems, and insight is needed into the effects of such strategies. Models have been used to quantify effects of strategies on sustainability, and in some cases resilience, of farming systems, but quantitative models are generally limited in the range of options and impacts they can explore. Participatory assessments allow to account for all relevant factors, and use local and expert knowledge to provide a thorough understanding.

In this study, we used insights from a participatory assessment (FoPIA-SURE-Farm 1 and 2) executed in in 11 EU farming systems to identify strategies that enhance sustainability and resilience of these farming systems. This participatory assessment was complemented by an expert assessment and system dynamics (SD) modelling, to improve understanding of dynamic processes influencing sustainability and resilience of farming systems, and the conditions that enable such processes. The main aim was to identify past and optional future strategies in farming systems across the EU, to assess how these contribute to the delivery of private and public goods and resilience-enhancing attributes, and to identify additional interventions needed by farming system actors and the enabling environment.

The approach followed nine steps. FoPIA-SURE-Farm 1 focussed on resilience of current systems, and in total 184 stakeholders participated in 11 workshops, while FoPIA-SURE-Farm 2 focussed on resilience of future systems, with a total of 130 stakeholders. We selected four steps from these workshops that contribute to our main aim: 1) identification of interacting thresholds across domains and scales, 2) identification of possible desired transformations of the farming system, i.e. alternative systems for the future, 3) impact assessment of status quo, system decline and alternative systems on eight farming system functions and a selection of resilience-enhancing attributes, and 4) identification of strategies that were applied in the past to cope with main challenges, and identification of strategies that contribute to reaching the proposed alternative systems in the future. In addition, researchers 5) assessed the contribution of strategies to 22 resilience-enhancing attributes, summarized in five principles, 6) identified actors involved, and 7) assessed the compatibility of status quo and alternative systems with 5 scenarios for European agriculture and food systems. Step 8) involved SD modelling to understand the mechanisms in alternative systems. Causal loop diagrams (CLD) were first developed for all 11 EU farming systems to synthesize interactions between challenges, system functions and resilience-enhancing attributes, and to show the influence of strategies. Next, these were synthesized in a general model. In step 9) the model was applied to assess impacts of and on resilience-enhancing attributes, including synergies and trade-offs.

Results showed that in many farming systems economic viability is threatened by environmental and economic challenges, leading to a smaller rural population and making it hard to maintain natural resources and biodiversity. Maintaining the status quo was judged to lead to a decline in the delivery of private and public goods. Identified alternative systems could be grouped into systems emphasizing improving economic, environmental or social functions. Whereas economic viability was on average expected to decline in the future if the status quo would be maintained, and largely decline if critical thresholds would be crossed, all proposed alternative systems were expected to at least improve economic viability. However, specifically the perceived impact on "biodiversity and habitat" largely differed depending on the alternative.

Strategies implemented in the past mainly aimed to strengthen the resilience-enhancing attribute "reasonably profitable", followed by "builds human capital", "socially self-organized", "infrastructure for innovation", "response diversity", "functional diversity" and "coupled with local and natural capital (production)". Strategies in the past were however perceived to improve the robustness of main indicators, but overall resilience of farming systems was judged to be low. In addition, maintaining the status quo was judged to lead to a decline in the delivery of private and public goods and resilience attributes. Hence, the identified alternatives systems are relevant directions to which the current systems could evolve to. When identifying strategies that are needed to reach alternative systems, which do have the potential to improve the delivery of private and public goods, the focus shifted to strengthening "coupled with local and natural capital", both regarding production and legislation. This implies that stakeholders consider these resilience-enhancing attributes as important for the future, and both new production practices and legislation are needed to improve sustainability and resilience. The increased focus on strengthening "diverse policies", "coupled with local and natural capital (legislation)", "appropriately connected with actors outside of the farming system", "coupled with local and natural capital (production)", "functional diversity" and "ecologically self-regulated" suggests that in the future more attention is needed for an enabling institutional environment, and also for attributes strengthening ecological processes.

SD modelling was used to further explore the dynamics in the alternative systems proposed, grouping them into systems that mainly improve economic, social or environmental functions. Results suggest that the alternative systems proposed by stakeholders specifically benefit of an environment that encourages and facilitates farmers' economic performance, social self-organization, and functional diversity. SD modelling also highlighted the importance to take a dynamic perspective and to consider how current responses and decisions affect long term resilience. Systems focused on economic functions may seem to enhance resilience in the short-term, but as these negatively affect many resilience attributes, in the long-term resilience may deteriorate, as there are 'limits to success'. The SD model shows that these limits to success are on the one hand determined by the potential degree into which a resource can effectively be turned into a desired good, and on the other hand determined by environmental and social feedback loops that need to be nurtured in order to sustain economic feedback loops. The SD model thus provides a strong suggestion for a balanced attention for economic, social and environmental dimensions.

Different alternative systems will thrive under different enabling environments, and therefore all may be feasible options, but this depends on future scenarios. When assessing the compatibility of current and suggested alternative systems with the five Shared Socio-economic Pathways for European agriculture and food systems (Eur-Agri-SSPs), it was concluded that most alternatives mainly thrive in the scenario ‘agriculture on sustainable paths’, while being specifically vulnerable in ‘agriculture on separated paths’. Therefore, flexibility is required to adjust the strategies according to the nature of future conditions.

While current strategies are often aimed at improving one function (e.g. “economically viable”) and/or resilience-enhancing attribute (e.g. “reasonably profitable”), sustainability and resilience can be improved when (a combination of) strategies improve multiple functions and attributes at once. All actors in the farming systems need to collaborate in order to make a change.

1 Introduction

Farming systems in the European Union (EU) are increasingly challenged by economic, environmental, social and institutional changes. Prices have become more volatile with liberalization of markets, and climate change has led to higher temperatures and more extremes including very dry summers in 2018, 2019 and 2020, resulting in yield reductions. Policies are constantly changing, with generally more attention for environmental issues such as greenhouse gas mitigation, biodiversity and nitrogen emissions, but not all farmers can keep up with the speed of change (Gomes, 2020; Spiegel et al., 2019). In the meantime, farm sizes are increasing and the number of farmers decreasing, resulting in less attractive rural areas (Mandryk et al., 2012; Pitson et al., 2020). Recently, the COVID-19 pandemic and resulting lock-downs caused a specific shock, notably for systems relying on catering, export and agritourism (Savary et al., 2020). All these shocks and stresses affect the sustainability and resilience of EU farming systems.

In 2019, the European Commission proposed The European Green Deal, which was further specified in the Farm-to-Fork and Biodiversity strategies (European Commission, 2019, 2020a, b, c), promoting the transition to sustainable and inclusive agricultural production. The European Green Deal is a comprehensive policy approach promoting transformation of the EU food system to be environmentally friendly, socially responsible, able to preserve ecosystems and biodiversity and to contribute to a climate-neutral European economy. It takes a holistic approach by targeting the whole EU food system from farmers to consumers by covering food production, transport, distribution, marketing and consumption as well as global trade and global food sustainability standards. Actions points are listed, but more knowledge is needed to identify which specific actions lead to a more sustainable and resilient agricultural system, and what is needed at local level.

A framework to assess the resilience of farming systems was developed by Meuwissen et al. (2019). Resilience of a farming system can be defined as its ability to ensure the provision of the system functions in the face of increasingly complex and accumulating economic, social, environmental and institutional shocks and stresses, through capacities of robustness, adaptability and transformability (Meuwissen et al. 2019). Sustainability is a concept complementary to resilience and refers to the adequate performance of all system functions across the environmental, economic and social domains (Morris et al. 2011). The framework includes five main steps: 1) identifying the resilience of what (farming system), 2) to what (challenges), and 3) for what purpose (functions and their sustainable performance level); 4) assessing the resilience capacities of robustness, adaptability and transformability; and 5) assessing attributes that contribute to the general resilience of a farming system, i.e. the system's capacity to appropriately respond to any kind of stress or shock.

This framework by Meuwissen et al. (2019) builds on resilience theory of socio-ecological systems, as inspired by Gunderson and Holling (2002). Gunderson and Holling (2002) proposed that most systems follow adaptive cycles, including stages of growth, conservation, release and reorganization (Figure 1). Adaptive cycles may not always occur and cannot always be clearly recognized, but, as a conceptual metaphor, it helps to think about different phases a system can go through (Cumming and Peterson 2017). During the growth phase, resources build up towards their potential and systems become more connected, resulting in a conservation phase with high productivity and efficiency, but also high rigidity, reducing resilience. As the stability domain contracts, the system becomes more vulnerable to shocks and stresses. A shock may then lead to release, in which accumulated resources, connections and feedbacks are released. During the reorganization phase, actors have fewer resources and connections are loose, but resilience is high as such conditions foster novelty and experiments. A new growth phase, in a new direction, can start. Systems do not go through all stages at equal speeds: the growth phase can be long and tortuous, while reorganization after release is often a quicker process (Burkhard et al., 2011; Tittonell, 2020; Walker and Salt, 2012). Further, not all processes in a system go through the same stage at the same time (Gunderson and Holling (2002), and therefore a collapse of a whole socio-ecological system is rare, and not desired. While resilience differs depending on the stage, it has also been argued that a system is only truly resilient if it can go smoothly through all stages of the adaptive cycle (Cabell and Oelofse, 2012; Fath et al., 2015).

Following this, three resilient capacities have been distinguished, as a system can respond to challenges in different ways: by coping with shocks and stresses (robustness), by actively responding to shocks and stresses without changing the system structure (adaptability), or by reorganizing its structure (transformability) (Folke et al., 2010; Ge et al., 2016; Meuwissen et al., 2019). Deliberate transformation requires resilience thinking, first in assessing the relative merits of the current versus alternative, potentially more favorable stability domains, and second in fostering resilience of the new development trajectory, the new basin of attraction (Folke et al., 2010). As suggested by Gallopin (2002), a truly sustainable and resilient system may represent an escape of the system towards another, qualitatively different, adaptive cycle. In such a system, adaptive cycles are smaller, shorter and more manageable (Figure 1). By reorganizing parts of the system, deliberate transformations may be achieved in the long-term.

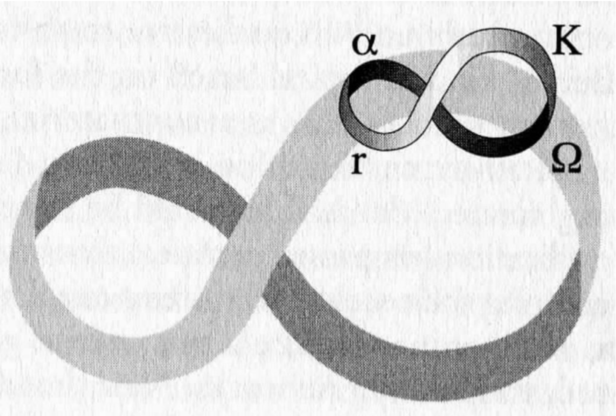

Figure 1. Does the path to sustainability imply adaptive cycles that are smaller, shorter and more manageable? (source: Gallopin, 2002). The figure represents the adaptive cycle, in which r refers to growth, K conservation, Ω release, and α reorganization.

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Within the framework by Meuwissen et al. (2019) a range of qualitative and quantitative methods was employed to investigate resilience in 11 EU farming systems. In this study, we used a participatory assessment (FoPIA-SURE-Farm 1 and 2) executed in in 11 EU farming systems to identify strategies that enhance sustainability and resilience of these farming systems. This participatory assessment was complemented by an expert assessment, and system dynamics modelling, to improve understanding of dynamic processes influencing sustainability and resilience of farming systems, and the conditions that enable such processes. The main aim was to identify past and optional future strategies in farming systems across the EU, to assess how these contribute to the delivery of private and public goods and resilience-enhancing attributes, and to identify additional interventions needed by farming system actors and the enabling environment.

2 Methods

2.1 Approach and case studies

In order to identify past and future strategies and their impacts on sustainability and resilience of farming systems, we use the resilience framework by Meuwissen et al. (2019) as a basis (Figure 2, ‘framework’). Participatory assessment, expert assessment and system dynamics modelling are used as methods. Results of the participatory assessments for 11 EU farming systems have been presented in detail in Reidsma et al. (2019) for current resilience (FoPIA-SURE-Farm 1) and in Accatino et al. (2020) for future resilience (FoPIA-SURE-Farm 2). In this report, we present the nine main steps that lead to an impact assessment of strategies, and the identification of resilience-enhancing strategies. We use the term strategies in relation to actions implemented by actors in- and outside the farming system. Past strategies refer to actions that have been implemented in the past to cope with main challenges affecting main functions of the farming system. Future strategies refer to actions suggested to maintain or reach a desired farming system in 2030. The assessments were done before the COVID-19 outbreak, and therefore do not consider strategies dealing with this shock. A specific assessment was performed regarding COVID-19 (see Appendix E).

Case study farming systems covered different sectors, farm types, products and challenges, and included large-scale arable farming in Bulgaria (BG-Arable), intensive arable farming in the Veenkoloniën region in the Netherlands (NL-Arable), arable farming in the East of England, United Kingdom (UK-Arable), large-scale corporate arable farming with additional livestock activities in East Germany (DE-Arable&Mixed), small-scale mixed farming in North-East Romania (RO-Mixed), intensive dairy farming in Flanders, Belgium (BE-Dairy), extensive beef cattle systems in the Massif Central, France (FR-Beef), extensive sheep farming in northeast Spain (ES-Sheep), high-value egg and broiler systems in southern Sweden (SE-Poultry), small-scale hazelnut production in central Italy (IT-Hazelnut), and fruit and vegetable farming in the Mazovian region, Poland (PL-Horticulture).

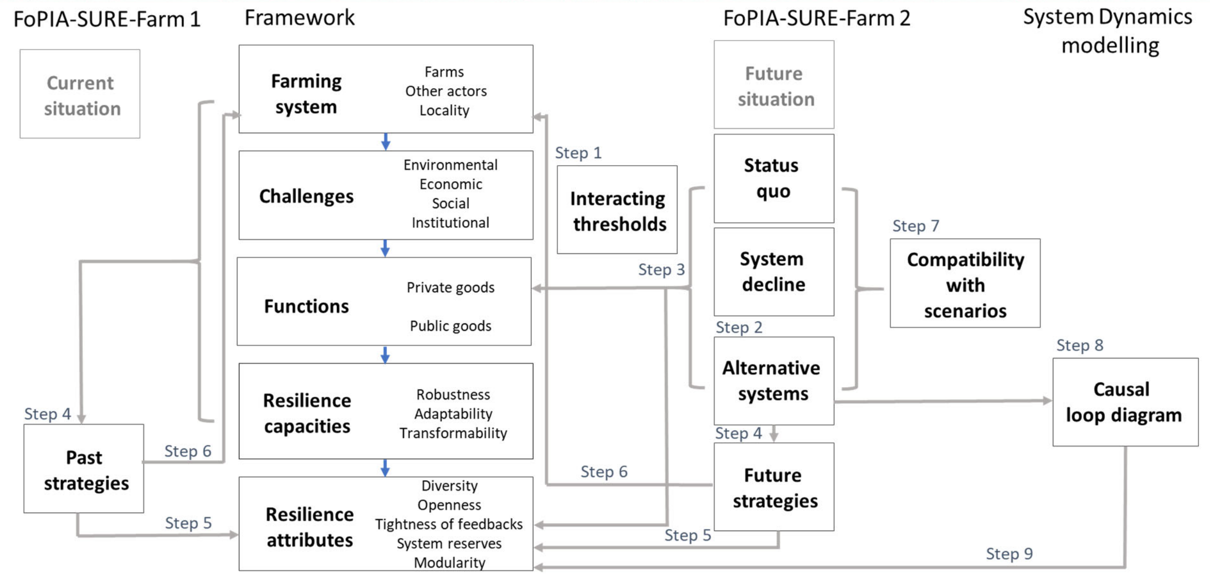

Figure 2. The framework to assess resilience of farming systems (Meuwissen et al., 2019), and steps taken in this report to identify strategies and their impacts on sustainability and resilience. Step 1-9 are described in section 2.3 and 2.4.

Impact assessments often use quantitative models (e.g. Helming et al., 2011; Herrera et al., 2018; Reidsma et al., 2015; Van Ittersum et al., 2008). Quantitative models are useful to simulate the impact of specific scenarios on specific indicators, but resilience of farming systems is too complex to be captured by single models (Accatino et al., 2020). For some indicators, accurate data and process knowledge are available, while for others data are lacking, and therefore such indicators are often ignored (e.g. the attractiveness of an area is difficult to capture with quantitative indicators). In addition, to assess resilience, dynamics of multiple processes need to be investigated simultaneously. It has earlier been argued that it is nearly impossible to account for every factor that contributes to resilience both now and in the future, and that using surrogate indicators is more useful than trying to measure resilience itself (e.g. Cabell and Oelofse, 2012; Darnhofer et al., 2010b). Qualitative approaches are needed to understand the dynamics of farms (Darnhofer, 2014). Therefore, to capture the full picture, and perform an integrated assessment, the assessment presented here is largely based on a participatory impact assessment. Participatory assessments allow to consistently follow all steps required in order to provide a holistic picture (Ashkenazy et al., 2018; Payne et al., 2019; Sellberg et al., 2017; Walker et al., 2002). Some steps were performed by experts (case study researchers) to ensure a good understanding of the concepts used. System dynamics modelling complements the participatory assessment to improve understanding of processes and to provide specific examples.

2.2 Participatory assessment

In FoPIA-SURE-Farm 1, the sustainability and resilience of current systems was assessed with stakeholders. In all the 11 case studies, workshops were held between November 2018 and March 2019 (Nera et al., 2020; Paas et al., 2019; Reidsma et al., 2020). The number of participants differed between 6 and 26, and represented farmers, industry, NGOs, government, research and advice, and others, with a total of 184 participants (Table 2 in Paas et al., 2019). In brief, the workshops focused on resilience and sustainability of current farming systems, focusing on 1) ranking the importance of functions (private and public goods) and selecting representative indicators for these functions, 2) scoring the current performance of the representative indicators, 3) sketching dynamics of main representative indicators of functions, 4) identifying which challenges caused these dynamics and which strategies were implemented to cope with these challenges, 5) assessing level of implementation of identified strategies and their potential contribution to the robustness, adaptability and transformability of the farming system, and 6) assessing the level of presence of resilience attributes and their potential contribution to the robustness, adaptability and transformability of the farming system.

FoPIA-SURE-Farm 2 focused on the resilience of future farming systems (Chapter 2 and Appendici in Accatino et al. 2020). Workshops were held between November 2019 and March 2020 in 9 case studies, and in 2 case studies desk studies were performed, as the COVID-19 crisis prevented the realization of the workshop. The number of participants ranged between 5 and 22, with a total of 130 participants, and represented similar groups as in FoPIA-SURE-Farm 1 (Table 2.1 in Accatino et al., 2020). The first half of the workshop was focused at maintaining the status quo and system decline. The second half of the workshop, on which this report is mainly building, was focused at alternative systems and strategies to realize these. Main research questions (RQ) included:

1. What are the current performance levels and trends of main indicators, resilience attributes and challenges of the farming system?
2. What is required to keep the current farming system in the future? (i.e. what boundary conditions need to be in place and what critical thresholds should be avoided to maintain the status quo?)
3. What will happen if the essential requirements are not met? (system decline)
4. What are possible desired transformations of the farming system? (alternative systems)
5. Given the likelihood of future states, are current strategies dedicated to the right issues?
6. What are underlying mechanisms causing farming system dynamics?
7. Are maintaining the status quo and proposed alternative systems compatible with Eur-Agri-SSPs?

2.3 Steps based on participatory assessment

We start with **step one**, which involved the synthesis of interactions between challenges, functions and attributes. Using input from FoPIA-SURE-Farm 1, in the FoPIA-SURE-Farm 2 process under RQ6, threshold interactions across domains (economic, social, environmental) and scales (field, farm, farming system) were visualized following the framework of Kinzig et al.

(2006). This visualization shows the main challenges that require the system to adapt and/or transform. Visualizations were made by researchers per case study, using inputs regarding critical thresholds for challenges, functions and resilience attributes. These were synthesized into one, summarizing interacting thresholds for EU farming systems.

As **step two**, we present the identification of alternative systems for the future. All participants in the FoPIA-SURE-Farm 2 workshops were asked to envisage one or more alternative states they desired if challenges would cross thresholds and/or functions and resilience attributes would need improvement (RQ4 in section 2.2). Stakeholders were asked for desired transformations, but adaptations were also accepted. Next, in a plenary session in each case study workshop an inventory was made on which alternative systems could be realized towards 2030. Suggestions by individuals were grouped into 2-4 alternative systems. Along with maintaining status quo, and system decline (when essential requirements are not met), these were considered to be possible future systems.

Subsequently, stakeholders were divided in small groups and within each group one alternative system was discussed with regard to main function indicators, resilience attributes, boundary conditions and strategies. This was input for **step three** of the current assessment, an impact assessment of future systems on eight farming system functions and 13 selected resilience-enhancing attributes. Impacts were classified as strongly negative (-2), moderately negative (-1), no trend (0), moderately positive (+1) and strongly positive developments (+2). These were averaged across case studies, and synthesized in arrows.

The fourth step was the identification of both strategies implemented in the past and strategies required to improve farming systems for the future. In FoPIA-SURE-Farm 1, strategies were identified that were applied in the past to cope with main challenges for main function indicators, using sketches of historical dynamics. In some case studies, the strategies identified in FoPIA-SURE-Farm 1 were complemented with strategies identified using other SURE-Farm approaches (e.g. Reidsma et al., 2019; Soriano et al., 2020). In FoPIA-SURE-Farm 2, the groups discussing alternative systems, also identified strategies that would be needed to reach the desired adaptations/transformations of the farming systems.

FoPIA-SURE-Farm 2 workshops yielded many relevant insights, but an additional step was required to assess the impact of strategies on resilience-enhancing attributes, which contribute to general resilience. Hence, in **step five** researchers linked the identified past and future strategies to 22 resilience-enhancing attributes (see Appendix A for full description). Similar to Soriano et al. (2020), resilience attributes were inferred based on statements regarding strategies, using the definition, implication and characteristics of the attributes (Appendix A). The 22 attributes are associated to the 5 general resilience principles (system reserves, tightness of feedbacks, diversity, modularity and openness; Appendix A; Meuwissen et al., 2019) and a synthesis from strategies enhancing these 5 principles was also made. The first two authors of this report did a first assessment across all case studies, this was checked per case study by case study partners, and evaluated again by the first two authors. Potential negative impacts of strategies on resilience attributes were also evaluated. Results contribute to one of the research questions of FoPIA-SURE-Farm 2 'Are strategies dedicated to the right issues?'. This relates to the overall aim of this report, to assess the impact of strategies on resilience.

In **step six**, researchers identified the actors required to implement the sustainability and resilience enhancing strategies, in order to identify what is required from different stakeholders. This is especially important with regard to access to resources (Duchek et al., 2019; Mathijs and Wauters, 2020). Actors need to allocate activate their resources, and decisions should be made on which strategies to prioritize. We focus on the main actor per strategy, although some strategies require multiple actors.

A farming system can be resilient to specific challenges (specified resilience), but this does not necessarily imply that the farming system is capable to deal with the unknown, uncertainty and surprise (general resilience). General resilience relates to the presence of resilience-enhancing attributes (Meuwissen et al., 2019), which were assessed in step five. In addition, general resilience also relates to the compatibility of farming systems with different future scenarios. Resilience-enhancing attributes are related to the farming system, but also to the enabling environment, which is influenced by scenario narratives. Mitter et al. (2019, 2020) developed 5 scenarios for European agriculture and food systems, called Eur-Agri-SSPs. In FoPIA-SURE-Farm 2 (Accatino et al. 2020), the compatibility of current and alternative systems with 5 Eur-Agri-SSPs was assessed. This is presented in **step seven** in this report, as it provides insight into how different systems and strategies may be needed in different scenarios.

For each future farming system, researchers of case studies indicated how important an increase in the SSP-indicators (related to Population, Economy, Policies & institutions, Technology and Environment & natural resources) as proposed by Mitter et al. (2020) was, where 0 is not important, 1 is somewhat important and 2 is very important. Expected developments of SSP-indicators were based on Mitter et al. (2020), with -1, 0 and 1 indicating negative, no and positive changes, respectively. Multiplication of the importance of positive developments for future systems with expected developments of SSP-indicators was used as an approximation for compatibility. Final compatibility scores per future system per SSP was an average of the overall section scores, 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.

2.4 From participatory assessments to a system dynamics approach

In **step eight**, a System Dynamics (SD) model was developed, and in **step nine** this model was used to explore the relations between strategies and resilience attributes. SD is a modelling method focused on studying how outcomes of the systems are driven by system's own internal mechanisms and the circular relationships (feedback loops) driving the outcomes of the system (Richardson, 2011). SD models can be used to understand and communicate what are the

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conditions that help a system to evolve into alternative configurations as well as how these alternative configurations affect resilience attributes that contribute to system wider resilience.

SD models can be used with different purposes. For instance, there are applications of SD where models are used to explore the effect of complex non-linear relationships on systems behaviour (see Dykes and Sterman, 2017; Moxnes and Saysel, 2005), explore scenarios (see Kapmeier and Gonçalves, 2018; Hosseini 2016), policy analysis (see Lane and Kopainsky, 2017; Sterman et al. 2012) and many others. For this report we use SD models as transitional objects that capture and summarise narratives provided by stakeholders in FoPIA-SURE-Farm workshops. For each case study, a casual loop diagram (CLD) was developed (see the FoPIA-SURE-Farm 2 reports in the supplementary material of Accatino et al., 2020). Using these CLDS as a starting point and stakeholders' more detailed contributions (see the FoPIA-SURE-Farm 2 reports in the supplementary material), we developed a general conceptual using the method described by Kim and Andersen (2012) as a systematic way to code qualitative text data to generate causal maps.

The aims for developing this model were:

a) linking variables mentioned by stakeholders during the FoPIA-SURE-Farm workshops in a coherent causal narrative,
b) identifying potential links from and to resilience attributes and
c) exploring feedback loop relationships that support adaptive mechanisms.

The relationships presented in the conceptual model mostly represent stakeholder perspectives and translate their narratives into causal hypothesis regarding how the system works and responds to changes in its operating environment. When needed, these narratives were complemented by descriptions found in the literature. For instance, we added causal relationships between variables if there was evidence in the literature strongly suggesting so, but stakeholders did not mention it during the workshops. Hence, the model combines both positive and interpretive paradigms of social science. The model "recognizes the existence of objective reality, but it also recognizes that actions intended to change the reality are generated by actors, each of whom owns a subjective perception of the reality" (Kim and Andersen, 2012, p.315). It is important to remark that our literature review on building the conceptual model was not exhaustive and some narratives and perspectives have been left out.

We started the development of the model by capturing the factors that affect profitability of farms. While we recognise that there is an increased awareness on the importance of the social and environmental functions farming systems perform (Ikerd, 1993; McCann et al., 1997; Timmer, 1997; Webster, 1997; Antle, 1999; Seyfang, 2006), using farm profits as the starting point makes it easy to operationalise farmers decision making process. It is a common assumption among economists that farmers make choices that are heavily driven by their desire to improve their profit by increasing their income as well as reducing their risk and labour requirements (Bowman and Zilberman, 2013; Stoorvogel et al., 2004). For example, the decision of investing in a particular strategy can be operationalised as a process that seeks to optimise "farm profits" (both in terms of magnitude and its stability) while meeting social and environmental constraints and aspirations.

Hence, we started by mapping the factors determining whether a farm is profitable. While each system is different and the importance of such factors depend on the type of activity, technology used and farmers management decisions (Bowman and Zilberman, 2013), it is still possible to make some generalisation. In the conceptual model "farm profits" are conceptualised as the farm sales (e.g. ton of crop sold, litre of milk sold) and the margin farmers make on these sales (e.g. €/ton, €/litre) as shown in Figure .

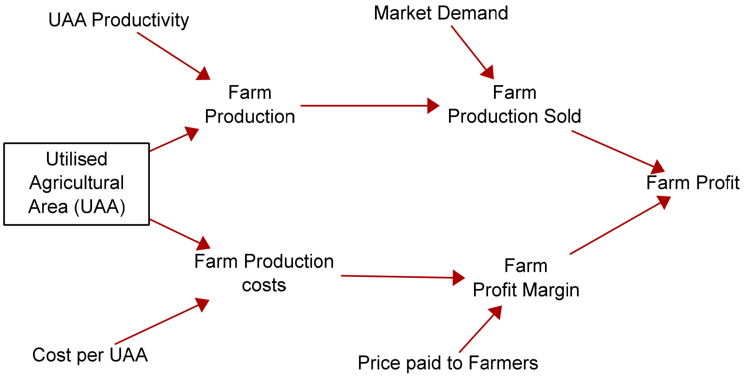

Figure 3. Farm profits are at the core of the synthesized system dynamics model for EU farming systems. Note that this is a minor part of the full model, which is presented in Appendix B.

Farm sales depend on the "farm production" (e.g. tons of meat, potato, maize) and the market demand for such production (see Figure 3). Farm production is conceptualised as a function of both the UAA and the "UAA productivity" (e.g. tons per ha, litres per ha). Correspondingly, the production costs have been expressed as a function of the "utilised agricultural area (UAA)" in the farming system and either "UAA productivity" for the farm production or the cost of keeping and operating a unit of UAA ("cost per UAA") as shown in Figure 3.

The rest of the model builds around this simple structure by searching what are the variables affecting and affected by "farm profits", as well as the social and environmental criteria that affect farmers decisions. These additional structures are added to the model either by adding variables or causal relationships highlighted by stakeholders or described in the literature. See Appendix B for an extensive explanation of the model and its development.

The model allowed us to explore system resilience from two perspectives. First it provided us with a map uncovering some mechanisms that farming systems might use to reconfigure themselves in response to challenges (Rammel and Van Den Bergh, 2003). Understanding these mechanisms is key to identify what are the attributes that contribute to such response. Second, it also allowed to hypothesise how these alternative configurations affect resilience attributes. This analysis opens an interesting line of enquire regarding trade offs between short term and long term resilience, and reliance at different levels (farm level vs. farming system level).

3 Results

3.1 Interacting thresholds across domains and scales

A large range of challenges affected the different farming systems (Accatino et al., 2020; Reidsma et al., 2019). Nevertheless, it appeared that main interactions across domains and scales were perceived to be similar across farming systems (Figure 4). In all case studies, economic viability at farm level was central, as it was threatened either by an increased frequency of extreme events lowering yields and/or increasing costs, and/or by low prices. In some case studies, this was amplified by the threat of pests and diseases, with nematode pressure in NL-Arable as main example. Yields were not necessarily decreasing, but as yields were often perceived to be close to critical thresholds for remaining profitable, a small yield reduction in a specific year was often seen as critical (see Chapter 2 in Accatino et al., 2020). While at a yearly basis, a lower yield may lead to a higher price, in the long term, both challenges amplify each other. The decrease in economic viability led to a lack of successors and the need to scale up, resulting in a smaller rural population. In addition, low economic viability made it difficult for farmers to invest in maintenance of natural resources and biodiversity. Hence, challenges in the economic and environmental domain had negative impacts on economic functions at farm level, which negatively impacted social and environmental functions at farming system level. Regarding the future, when critical thresholds are passed, all system functions and most resilience attributes are expected to decline (see section 3.3, system decline).

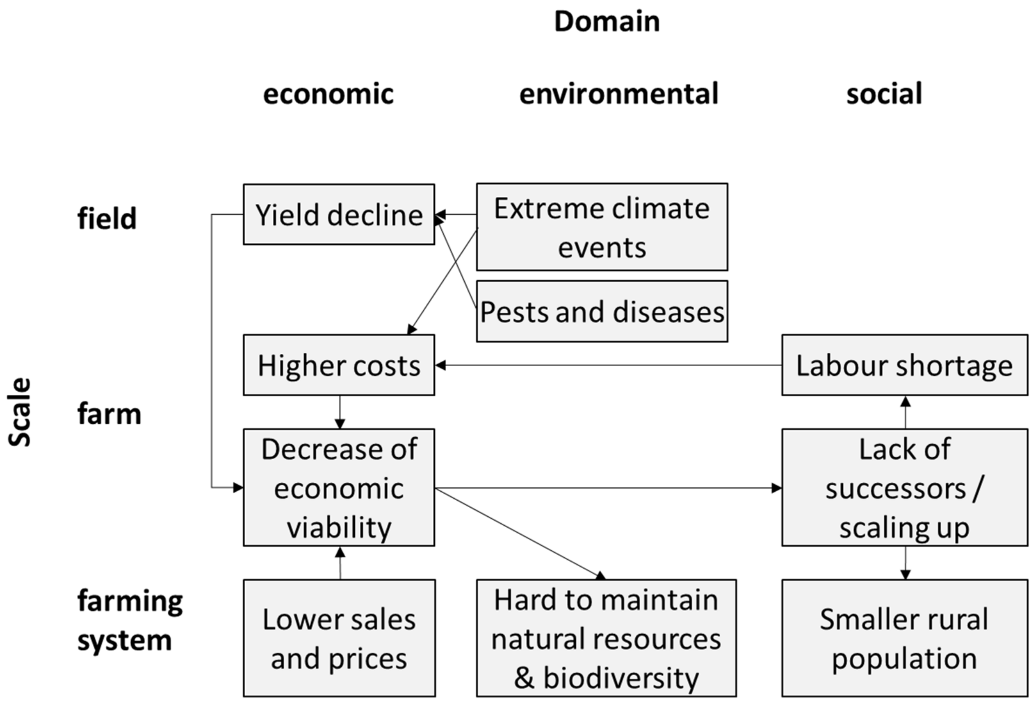

Figure 4. A synthesis of main interactions across scales and domains across 11 EU farming systems (based on the framework of Kinzig et al. (2006) and results from case study reports in Accatino et al. (2020). Note that more interactions may be present than the ones presented in the figure.

This Project has received funds from the European Union’s Horizon 2020 research and innovation programme under Grant Agreement No. 727520

3.2 Alternative future farming systems

As maintaining status quo in the future was expected to lead to a further decrease in "economic viability" and "attractiveness of the area" in many of the 11 EU farming systems, resilience attributes would not be improved, and passing critical thresholds could lead to system decline for all system functions and resilience attributes (see section 3.3), alternative systems were identified for the future. Many alternative systems seem to be adaptations rather than transformations of current systems. They could broadly be grouped in eight categories (Table 1; Chapter 2 in Accatino et al., 2020) with three main directions: 1) intensification / specialization / technology / product valorization with a focus on improving production and economic functions and attributes, 2) collaboration / attractive countryside, with a focus on improving social functions and attributes, and 3) diversification /organic / nature friendly with a focus on improving environmental functions and attributes. In relatively more extensive systems like DE-Arable&Mixed, RO-Mixed, ES-Sheep and PL-Horticulture alternative systems focused on intensification or specialization were seen as viable options. Also in SE-Poultry further intensification was considered as an option. Many case studies considered alternatives which focused on technology development as viable options, but generally this technology should also allow to improve the maintenance of natural resources and biodiversity (e.g. precision agriculture). In several case studies, alternatives focusing on collaboration among actors in- and outside of the farming system were specifically identified, emphasizing the need for social interaction in order to improve other functions. Lastly, all case studies identified alternatives in relation to diversification and nature friendly agriculture, focusing on improving environmental functions and attributes (however, for ES-Sheep grouped under technology). The decrease in environmental performance was a concern in all case studies (Paas et al., 2019; Accatino et al., 2020).

Clearly, the categories are not mutually exclusive, e.g. organic / nature friendly could be combined with a change towards diversification (NL-Arable) or specialization (PL-Horticulture). In most case studies, alternative systems were perceived as compatible with one another at the same time at farm and/or farming system level (DE-Arable&Mixed, NL-Arable, SE-Poultry, IT-Hazelnut, ES-Sheep), and/or over time at the farming system level (UK-Arable, NL-Arable). For most arable systems in this study and for IT-hazelnut, alternatives that are driven by improved product valorization are compatible with a shift towards more nature-friendly and/or organic agriculture (DE-Arable&Mixed, NL-Arable, IT-Hazelnut).

Table 1. Alternative systems per category per case study. Categories are based on the most important direction that an alternative system is taking, according to the interpretation of the research team in each case study. Categories are hence not mutually exclusive and alternative systems can have elements of multiple categories (source: Table 2.9 in Chapter 2 of Accatino et al. 2020).

	Case studies										
Category	BG-Arable	NL-Arable	UK-Arable	DE-Arable&Mixed	RO-Mixed	ES-Sheep	FR-Beef	SE-Poultry	PL-Horti-culture	IT-Hazelnut	Total[1] (n)
Intensification				Intensification		Semi-intensive		Large farms			3
Specialization					Commercial specialization of family mixed farms		Only-for-export production		Horticulture farming		3
Technology	Innovation and technology	Precision agriculture				Hi-tech extensive		Robots	Shelter farming	Technological innovation	6
Product valorization	Processing and increasing added value						Production only for the French market			Product valorization	3
Collaboration	Collaboration	Collaboration & water			Cooperation / multifunctionality						3
Attractive countryside				Better societal appreciation			Development of tourism			Sustained demand (high and stable prices)	3
Diversification	Crop diversification	Alternative crops	Likely system		Alternative crops / livestock			Self-sufficiency fodder			5
Organic / nature friendly		Nature-inclusive	Desirable system	Organic farming	Organic agriculture				Local organic farming	Eco-friendly agriculture	6
Total (n)	**4[2]**	**4**	**2**	**3**	**4**	**2**	**3**	**3**	**3**	**4**	**32**

[1] For BE-Dairy and FR-Beef, desk studies were conducted instead of workshops. For FR-Beef alternatives were identified, for BE-Dairy the focus was on the status quo.

[2] In BG-Arable, participants also considered ‘Exiting farming / change of sector’ and ‘Moving the farm to a different region’ as alternatives, but these are not included in this table.

3.3 Impact assessment of current and alternative systems

The impact assessment of remaining in the status quo and of system decline (Table 2) confirms Figure 4. When maintaining status quo, on average indicators representing “economic viability” and “attractiveness of the area”’ were expected to decrease. In the one case study where “quality of life” was discussed (DE-Arable&Mixed), the provision of this function was also expected to largely decrease. On average, no large change were expected for resilience attributes, except for “reasonably profitable” and “appropriately connected with actors outside of the system”. When critical thresholds would be exceeded, and system decline would take place, almost all functions and attributes were expected to be negatively affected.

Table 2. Developments of system indicators per function and resilience attributes for the status quo, system decline and minimum and maximum developments in alternative systems. Arrows down (↓) imply strong negative, down-right (↘) moderate negative, straight (→) stable, right-up (↗) moderate positive, and up (↑) strong positive developments, with others in-between (Based on: Table 2.11 in Chapter 2 in Accatino et al., 2020).

			Expected average developments in future systems			
Function/resilience attribute	Name	Number of times discussed	Status quo	System decline	Minimum of alternative systems	Maximum of alternative systems
Function	Food production	8	→	↘	→	↗
	Bio-based resources	2	→	↘	→↗	↗
	Economic viability	11	→↘	↘	→↗	↗
	Quality of life	1	↘	↓	↘	↑
	Natural resources	7	→	↘	→	↗
	Biodiversity & habitat	4	→	→↘	→	↑
	Attractiveness of the area	4	→↘	↘↓	→↗	↗
	Animal health & welfare	2	→↗	→	→↗	↗
Resilience attribute	Reasonable profitable	4	→↘	↘	→↗	→↗
	Production coupled with local and natural capital	5	→	↘↓	↗	↗↑
	Functional diversity	3	→	→	→	→↗
	Response diversity	3	→	↘↓	→	↗
	Exposed to disturbance	3	→↗	↗	→	→↗
	Spatial and temporal heterogeneity (farm types)	2	→↗	→↗	↘	↗
	Support rural life	4	→	↘	→↗	↗
	Socially self-organized	5	→	↘	→↗	↑
	Appropriately connected with actors outside the farming system	2	→↘	→↘	→↗	↑
	Coupled with local and natural capital (legislation)	1	→	→	↗	↗
	Infrastructure for innovation	7	→	→↘	↗	↗↑
	Diverse policies	2	→	→↘	↗	↗↑

[1] For BE-Dairy and FR-Beef, desk studies were conducted instead of workshops and results from these case studies are hence not included in this table.

When selecting the smallest and largest expected effects of all alternative systems per case study, one could argue that the minimum and maximum potential for change can be assessed

(Table 2). Minimum and maximum positive developments of farming system functions indicate that for most functions at most moderate improvements are expected. For "food production", "natural resources" and "biodiversity & habitat", minimum developments were expected to be stable, suggesting that these functions cannot be improved in all alternative systems. For "quality of life" (discussed once) and "biodiversity & habitat" (discussed four times), the average maximum development is expected to be strongly positive, while the average minimum development is expected to be negative. This indicates that for these functions, alternative systems seem to take different directions.

Under alternative systems, "food production" is perceived to at least not to change and at most moderately improve. For "economic viability" negative developments under status quo are expected to at least be countered by alternative systems and at most be turned into moderate positive developments. For "natural resources", expected stability under status quo across case studies is expected to become at least slightly improved and at most moderately improved by alternative systems. In UK-Arable, negative developments for indicators representing "quality of life" and "biodiversity & habitat" were expected to be kept going in the least radical alternative system, which was also considered to be the most likely one. In three case studies, some alternative systems resulted in negative developments for food production (BG-Arable), economic viability (BG-Arable and SE-Poultry) and natural resources (SE-Poultry, NL-Arable), implying a trade-off as overall performance of main indicators was expected to improve.

Minimum and maximum positive developments were expected to be stronger for resilience attributes than for functions. This suggests that stakeholders have more trust in the ability to improve resilience attributes than in the effect this will have on improving the performance level of system functions. In particular, "production coupled with local and natural capital" and "infrastructure for innovation" were often discussed and expected to show moderate to strong positive developments in proposed alternative systems. The maximum was high, but also the minimum was relatively high, suggesting that stakeholders considered these attributes as prerequisites for alternative systems. Also "socially self-organized" and "appropriately connected with actors outside of the system" showed large potential for improvement in alternative systems.

3.4 Identification of past and future strategies

Strategies that were mentioned by participants to be implemented in the past and suggested for future alternative systems (see Appendix C for a complete overview) had different degrees of specificity: some strategies were umbrella strategies and overarched a set of more specific challenged, while other strategies were very specific and linked to one domain. Across case studies, 112 strategies were identified to be implemented in the past to enhance resilience of current systems, and an additional 88 were identified to reach alternative systems.

While many past strategies focused on the economic domain, relatively few additional strategies of this domain were identified for alternative systems. In many case studies, past strategies like diversification of income sources (ES-Sheep, FR-Beef, RO-Mixed, UK-Arable) remained relevant in least one of the alternative systems. Other strategies that had been important in the past, were considered less relevant for the future. For example, in NL-Arable, three out of four alternative systems maintained a focus on economic strategies, but the nature of the strategies shifted from scaling up production and cost reduction towards developing a new business model.

While relatively few institutional strategies were identified for the past, the institutional domain received most attention when identifying strategies required to reach alternative systems. Typically suggested future strategies in the institutional domain imply a better cooperation with actors inside and outside the farming system (BG-Arable, UK-Arable, RO-Mixed), strategies regarding the protection and promotion of its products (ES-Sheep, De-Arable&Mixed, PL-Horticulture, IT-Hazelnut), regulations specified for the farming system to avoid mismatches (DE-Arable&Mixed, ES-Sheep, NL-Arable, RO-Mixed), , simplification and/or relaxation of regulations (PL-Horticulture, DE-Arable&Mixed, NL-Arable), rewarding the delivery of public goods (NL-Arable, ES-Sheep) or financial support in general (PL-Horticulture, IT-Hazelnut, RO-Mixed).

Agronomic strategies included amongst others improved knowledge and research on crops and livestock (NL-Arable, ES-Sheep, SE-Poultry, DE-Arable&Mixed, RO-Mixed), and implementation of more technology (see Appendix C and case study reports in Accatino et al., 2020).

Strategies primarily aimed at the social domain were mentioned in all case studies, except for SE-Poultry. In SE-Poultry, stakeholders argued that knowledge sources were available and that these were used to a good extent. Strategies in the social domain included amongst others cooperation and/or knowledge sharing among farming system actors (in a value chain and/or cooperative) (all case studies having socially oriented strategies), learning, education and/or awareness raising strategies for actors inside the farming system (UK-Arable, NL-Arable, IT-Hazelnut, BG-Arable, RO-Mixed) or aimed at producer-consumer connections (PL-Horticulture, NL-Arable, ES-Sheep).

3.5 How do past and future strategies impact resilience-enhancing attributes?

When assessing how strategies that have been implemented to cope with challenges in the past ('strategies for current systems') contributed to resilience attributes (Figure 5; see Appendix A for explanation of attributes), we observe that 38% of the strategies positively contributed to "reasonably profitable". Many strategies also contributed to "builds human capital", "socially self-organized", "infrastructure for innovation", "response diversity", "functional diversity" and "coupled with local and natural capital (production)". For these attributes negative developments were expected when maintaining status quo (Table 2), while they were considered important for resilience capacities (Paas et al, 2019; Reidsma et al. 2020).

There seems to have been a lack of attention for improving “optimal redundancy of crops, nutrients and water”, and for the “spatial heterogeneity at landscape level”.

When identifying strategies to reach alternative systems (Figure 5), there was relatively most focus on strengthening “coupled with local and natural capital”, both regarding production and legislation. The following attributes were more often strengthened when compared to strategies already implemented: “diverse policies” (although on average not mentioned often), “coupled with local and natural capital (legislation)”, “appropriately connected with actors outside of the farming system”, “coupled with local and natural capital (production)”, “functional diversity” and “ecologically self-regulated”. This suggests there is more attention for the enabling institutional environment when identifying required strategies for the future, but also for attributes strengthening ecological processes.

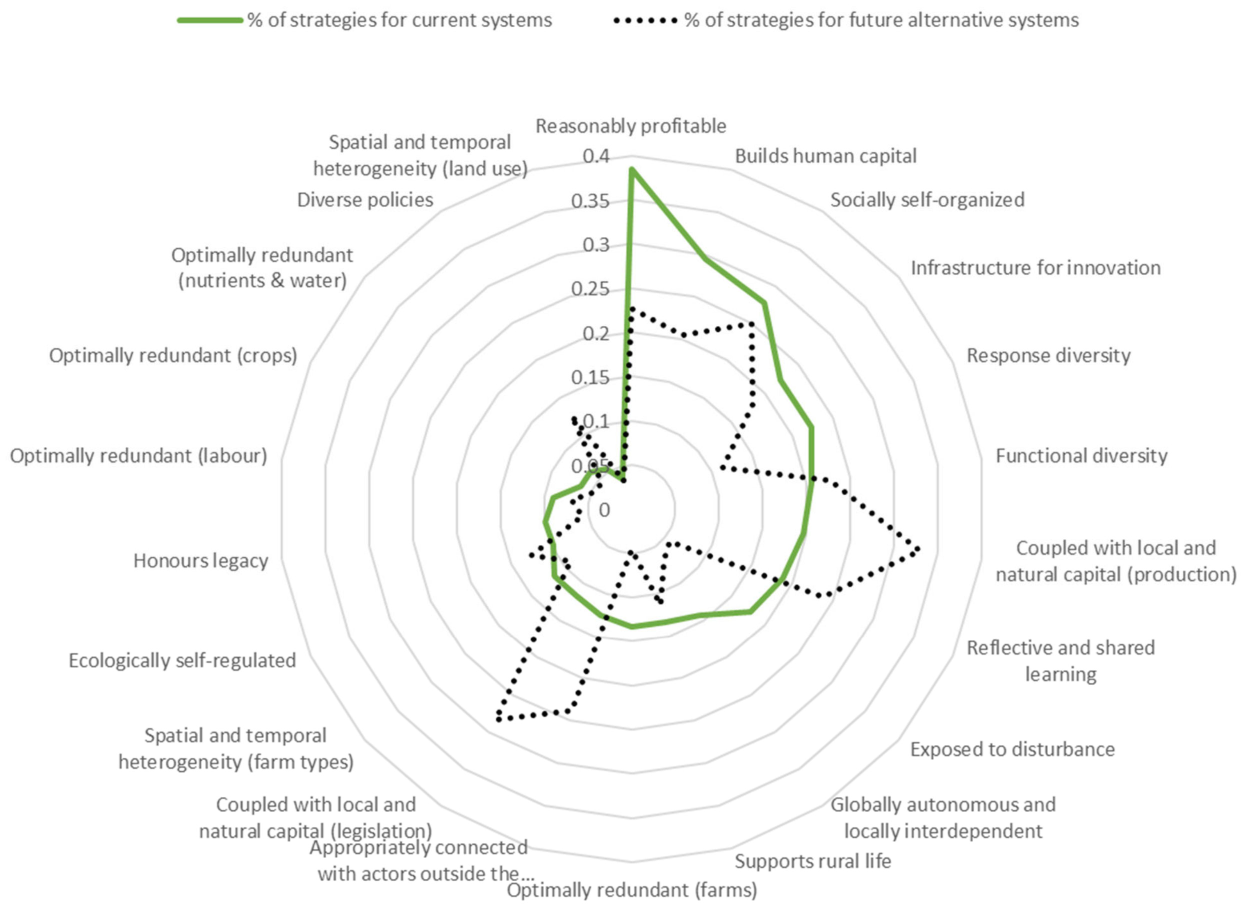

Figure 5. The contribution of identified strategies to resilience attributes. An expected positive impact was scored as 1, and no impact as 0; effectiveness was not assessed. Attribution is not mutually exclusive, i.e. one strategy can positively impact multiple attributes. The green line shows the ratio of (past) strategies implemented for current systems contributing to an attribute, and the black dotted line the ratio of future strategies for alternative systems contributing to an attribute. Attributes are ordered, starting with the attribute to which most past strategies contributed.

Resilience attributes that are most enhanced by current strategies ("reasonably profitable", "socially self-organized", "infrastructure for innovation", "response diversity", "coupled with local and natural capital (production)" and "functional diversity") are also the ones that were considered most important for the resilience capacities robustness and adaptability in FoPIA-SURE-Farm 1 (Reidsma et al., 2020). "Infrastructure for innovation" was earlier identified to be specifically important for transformability, but this attribute was not specifically stressed by strategies for achieving alternative systems. While the portfolio of strategies identified in different case studies contributed to all resilience attributes, some did receive less attention. For example, "optimally redundant farms" and "supports rural life" were not strengthened much by either past or future strategies, while Figure 4 suggested that scaling up and the lack of successors leading to a smaller rural population was a concern in most case studies. Table 2 also suggested that particularly the functions related to the social domain "quality of life" and " attractiveness of the rural area", which were discussed in five case studies, were threatened when maintaining status quo. The lack of strategies focussing on these social functions, requires attention. Figure 6 also confirms that in general, the principles modularity and diversity require more attention.

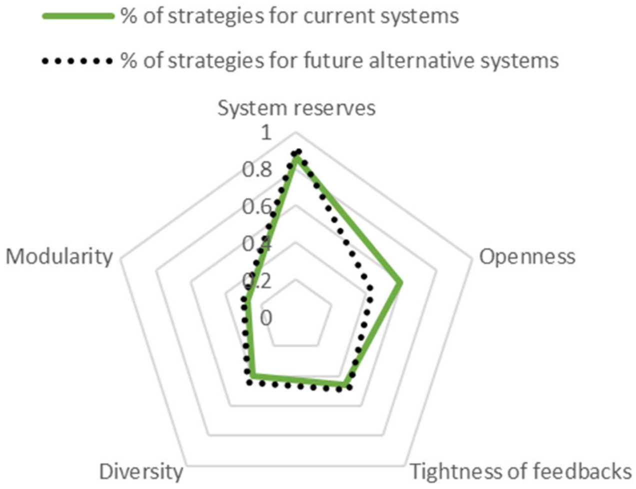

Figure 6. The contribution of identified strategies to resilience principles. Positive contributions to resilience attributes were translated to principles using Table A1 in Appendix A. The green line shows the ratio of (past) strategies for current systems contributing to a principle, and the black dotted line the ratio of strategies for future alternative systems contributing to a principle. Principles are ordered, starting with the principle to which most strategies contributed.

Potential negative contributions to resilience attributes were judged to be less frequent than the potential positive contributions (Figure 7). Nevertheless, while "reasonably profitable" was often strengthened on the one hand, also negative impacts were foreseen, showing that trade-offs among resilience attributes might lead to unintended consequences. Negative contributions were particularly foreseen for attributes related to diversity and redundancy. Hence, while on the one hand, few strategies enhanced such attributes, some implemented and proposed strategies may also negatively affect these. Few strategies were expected to have negative contributions to social and institutional attributes, but "honours legacy" was perceived to be at risk for some of the future strategies.

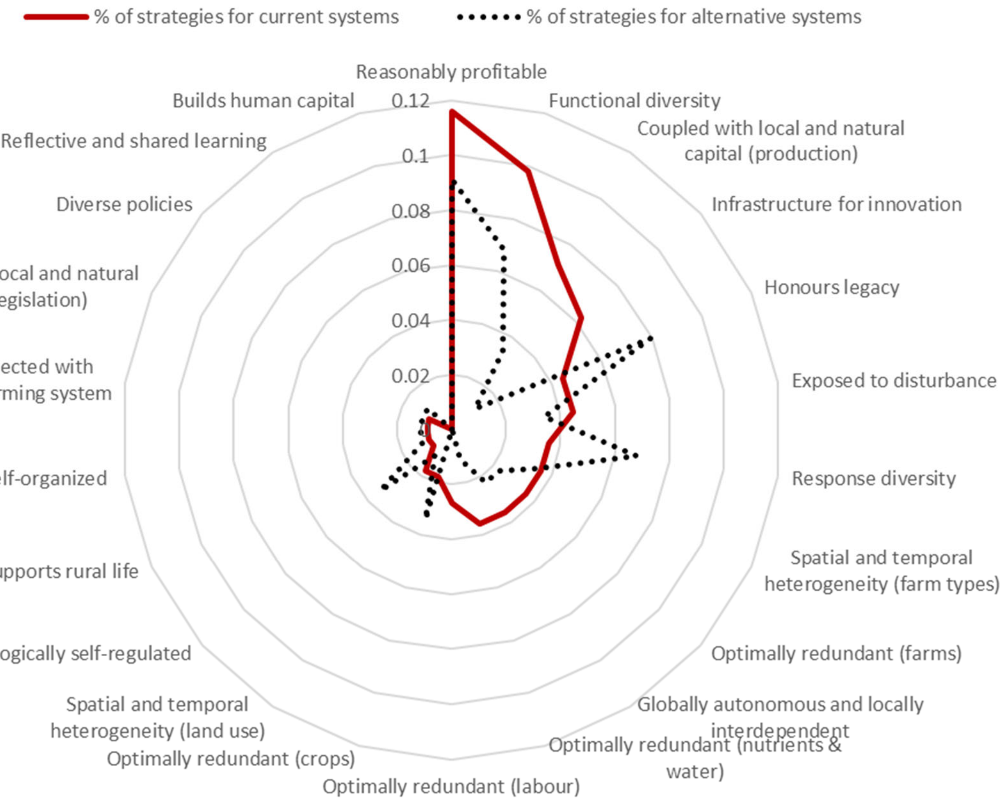

Figure 7. Negative contributions of identified strategies to resilience attributes. An expected negative impact was scored as 1, and no impact as 0; effectiveness was not assessed. Attribution is not mutually exclusive, i.e. one strategy can negatively impact multiple attributes. The red line shows the ratio of all strategies potentially contributing negatively to an attribute, and the orange line the ratio of strategies for alternative systems negatively contributing to an attribute. Attributes are ordered, starting with the attribute to which most strategies contributed negatively.

3.6 Which actors need to implement strategies?

Most strategies need to be first of all implemented by farmers (Table 3), as was earlier concluded by Meuwissen et al. (2020). Action is also requested from the government, enterprises and AKIS (Agricultural knowledge and information systems). Few strategies that require action from the intermediary and social domain were identified. Strategies to reach alternative systems more often require action by the government, again stressing the importance of the enabling environment (see section 3.5).

This Project has received funds from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 727520

Table 3. Main actors that are expected to implement the strategies. Each strategy was linked to one main actor. Higher values are coloured in darker green.

	A: ratio of total number of strategies	B: ratio of strategies for alternative systems	B/A: alternative/total
Farmer	0.37	0.30	0.36
Government	0.25	0.39	0.79
Enterprise	0.18	0.15	0.37
Intermediary	0.06	0.03	0.27
Social	0.01	0.01	1.00
AKIS	0.15	0.13	0.38

The observation that few strategies were identified as requiring action by the intermediary and social domain, may be related to the limited change that proposed alternative systems bring and the current perceived independence on local communities and the disconnection between producer and consumer. In Reidsma et al. (2020) we also concluded that farming system actors generally lack attention for the social domain. In a way, actively involving the actors from the intermediary and social domain, would imply radical change. Often heard comments of farmers is that consumers are not prepared to pay for good products, do not know about agriculture, etc. Localizing production and consumption (as proposed in a few case studies) may resolve some of these issues, but is apparently not the preferential choice in many systems.

It should be noted that some of the strategies were broad, and different actors instead of one main actor are involved, which could include the intermediary and social domain. Clearly, more is expected from the government in the future, and the government can instigate actions by the aforementioned actors to ensure "sustainable" resilience in the long-term.

3.7 Compatibility of farming systems with future scenarios

After the workshops, research teams evaluated the compatibility of possible future systems with scenarios for European agriculture and food systems, the Eur-Agri-SSPs (Mitter et al., 2019, 2020) (Table 4). Requirements of future systems, regarding indicator improvement, avoidance of thresholds, presence of boundary conditions and implementation of strategies were compared to developments of indicators in Eur-Agri-SSPs related to population, economy, policies & institutions, technology and environment & natural resources. Eur-Agri-SSPs are not downscaled to the level of individual farming systems. Still, compatibility of future systems with multiple scenarios indicates flexibility of such systems and may reveal what future system is "the safest bet", or for what scenario no feasible future system was proposed.

Most future systems, including maintaining the status quo, seem to be most compatible with SSP1 "Sustainability pathways". This is mainly due to favourable developments regarding policies and institutions and technology, corresponding with boundary conditions and strategies in most future systems. Also, developments in the population may increase compatibility as citizen environmental awareness is expected to increase and the rural-urban linkages to be strengthened. This is however not important for all alternative systems. For instance, alternative systems that focus on specialization in PL-Horticulture and RO-Mixed depend less on developments related to population. For most arable systems, developments regarding the environment and natural resources are also favourable and help to avoid further degradation beyond critical thresholds, e.g. regarding soil quality. The need for improving soil quality also explains lesser compatibility with other SSPs for arable systems compared to other studied farming systems. It should be noted that too much attention for environmental performance might threaten certain crops that under conventional cultivation depend on crop protection products, e.g. potato. Alternative systems primarily driven by organic/nature friendly production, product valorization, but also intensification seem to be most compatible with SSP1.

Table 4. Average compatibility of alternative system categories with Eur-Agri-SSPs. Where 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. Colours reflect compatibility categories. Aggregated results from nine case studies (Source: Table 2.14 in Accatino et al., 2020).

		Average compatibility score				
Category future systems	Future systems [#]	SSP1 "Sustain-ability"	SSP2 "Status quo"	SSP3 "Regional rivalry"	SSP4 "Inequality"	SSP5 "Technology"
Status quo	9	0.55	0.31	-0.59	0.15	0.29
Intensification	3	0.67	0.48	-0.29	0.21	0.28
Specialization	2	0.50	0.36	-0.67	0.24	0.37
Technology	6	0.63	0.32	-0.50	0.22	0.26
Product valorization	2	0.68	0.26	-0.80	0.01	0.22
Collaboration	3	0.63	0.26	-0.76	0.16	0.24
Attractive countryside	1	0.81	0.36	-0.69	-0.09	0.24
Diversification	6	0.63	0.30	-0.48	0.17	0.25
Organic / nature friendly	6	0.72	0.37	-0.74	0.11	0.21
Average[1]		**0.63**	**0.33**	**-0.59**	**0.15**	**0.26**

[1] *For BE-Dairy and FR-Beef, desk studies were conducted instead of workshops and results from these case studies are hence not included in this table.*

With regard to environmental developments needed for at least maintaining the status quo, it becomes clear that SSP2 "Status quo" will not bring the developments that are needed to avoid exceeding environmental thresholds in the arable systems. Still, supported by generally positive developments in the economy, policies and institutions and technology, most case studies are weakly compatible with SSP2. However, for case studies where scaling and further intensification was seen as a possibility for the future (ES-Sheep, SE-Poultry, RO-Mixed, BE-Dairy), SSP2 seems to be moderately compatible.

In SSP3 "Regional rivalry" most rural-urban linkages, infrastructure, export, trade agreements, institutions, technology levels and maintenance of natural resources are expected to decline, which is only expected to be compensated by increased commodity prices and direct payments. SSP3 seems, therefore, most incompatible with most future systems in all case studies, especially because of the exporting nature of many case studies and/or the need for technology and maintenance of remaining natural resources. SE-Poultry is an exception to this, because of the current experienced mismatch of Swedish national food production quality requirements and EU free trade agreements. SE-Poultry is mainly producing for its own national market. Closing borders and decreased trade agreements would consequently imply an increase in a competitive advantage over cheaper produced, lower quality products from other countries. Loss of competitive advantage because of mismatches between regulations was also mentioned by participants in DE-Arable&Mixed and PL-Horticulture, but only to a limited extent.

SSP4 "Inequality pathways" shows a mix of positive and negative developments. Population indicators, such as rural-urban linkages are expected to decrease while technology levels are expected to go up. Indicators related to economy and policies and institutions are showing both positive and negative developments. In SSP4, further depletion of natural resources is expected, but probably at a slower rate due to increased resource use efficiency. Altogether, future systems are weakly compatible with the developments in SSP4. Alternative systems primarily driven by intensification, specialization or technology seem to be most compatible with this SSP.

Alternative systems seem only weakly compatible with SSP5 "Technology pathways". In SSP5, technology levels will generally increase, but not necessarily made available to agriculture, which is partly why alternative systems primarily driven by technology are not the most compatible alternatives.

Concluding, even though some systems seem more resilient than others, none of the systems can cope with all kinds of challenges. Especially in SSP3, according to the scenario narrative, many resilience attributes are eroded. Boundary conditions for current and alternative systems are thus not present. It is difficult to be a resilient farming system in a non-resilient world. However, the compatibility scores are averages across complementarity with different elements of the narratives. Farming systems may be compatible with some, but not with other elements. A strategy can focus on improving such an element; even though at European level such an element is not compatible, at local level actors can change this in the local context.

3.8 From participatory assessments to system dynamics: mechanisms in alternative farming systems

The conceptual SD model that has been developed is described in detail in Appendix B. For this analysis we used the model to explore which mechanisms in the system might play an important role in farming system development towards the three directions identified earlier in section 3.2:

1. Alternative systems with a focus on improving production and economic functions

2. Alternative systems with a focus on improving social functions
3. Alternative systems with a focus on improving environmental functions

We split these mechanisms into two main categories: driving mechanisms (or mechanisms that will reinforce system development in that direction) and limiting mechanisms (mechanisms that will hinder system development in that direction). The results of our analysis using the conceptual model are summarised in Table 5.

In alternative systems with a focus on improving production and economic functions, farm profits are mainly used by farmers to increase their production throughput by either investing in increasing the size of their farm (see R1 in Figure B1), investing in technologies that increase their land productivity (see R2 in Figure B1) or increasing product valorisaton (see R4 in Figure). As discussed in Appendix B, the success of these strategies is constrained by their economic feasibility, the market demand and the land available for farm expansion. These constraints are not static and policies that aim to promote these alternative systems might focus on ways to relax them. For example, new trade agreements can be used to open new markets and increase demand or subsidies can be applied to new technological developments reducing the costs of acquiring, maintaining and updating farms' technology.

There are also important trade-offs to consider between private and public goods when considering these alternative configurations of the system. For example, while some farms, likely those with a better access to resources, will get bigger and more productive, less successful ones will be driven out of the system. Unsurprisingly, farming systems with a focus on production are more likely to have a smaller number of farmers, larger monocultures and offer less jobs than otherwise.

Alternative systems with a focus on improving social functions are also driven, to some extent, by farm profits and the extent to which developing human capital could increase farm productivity and profits (see R3 in Figure). Higher profits can be used to develop even higher human capital by investing in training and/or recruiting more qualified staff that eventually contribute to improving the farm's productivity.

Higher human capital might contribute to improve the attractiveness of rural areas potentially breaking some negative stereotypes associated with farming (e.g. low paid jobs). The attractiveness of rural areas and higher incomes for farmers could be expected to lead to higher succesion rates among farmers and, potentially even to more new entrants. Having more farmers increases diversity of thinking, foster opportunities for cooperation and learning that eventually contributes to human capital development (see R10 in Figure B6.B6).

Land and economic feasibility are the main constraints for this direction as a) there is only a certain number of farms and farmers that can operate within the system boundaries (see B11 and B12 in Figure B6.B6) and b) there are limits to the extent human capital can improve farm productivity (see B15 in Figure B8.B8).

Table 5. Main feedback loops affecting the development of the alternative systems (for codes of feedback loops, for the loops see Appendix B).

Alternative system with a focus on:	Driving feedback loops	Main limiting feedback loops
Improving production and economic functions	R1 (Increasing agricultural area) R2 (mechanisation/automation) R4 (product valorisation)	B1 (market equilibrium) B10 (land constraining number of farms) B12 (farm area number of farms) B13 (rural population constraining land available for agriculture) B14 (maximum productivity can be achieve with technology) B7 (product valorisation reducing pressure to increase profits) B16 (maximum product value that can be achieved) B17 (marginal increase of price with increase value) B18 (capital increasing production costs)
Improving social functions	R3 (investment in human capital) B6 (self-organization facilitating learning) B7 (self-organization supporting product value) R10 (farmers diversity increasing human capital)	B8 (number of farmers constraining learning) B9 (price of land constraining farm area) B11 (number of farms constraining farm area) B12 (farm area number of farms) B15 (maximum productivity can be achieve with human capital)
Improving environmental functions	R4 (product valorisation) R5 (residues increasing organic matter) R6 (environmental pressure driving eco-friendly practices improving soil quality) R7 (environmental pressure driving eco-friendly practices improving water management)	B3 (water available constraining production) B4 (organic matter constraining production) B6 (profitability reducing alternative source of income) B7 (product valorisation reducing pressure to increase profits) B19 (cost of eco-friendly technologies constraining its implementation)

Alternative systems with a focus on improving environmental functions have mostly exogenous drivers (e.g. social pressure, changes in consumption patterns, changes in environmental awareness, regulations) because environmental impact happens at a wider scale than the scale of the farming system itself (e.g. climate change is global phenomena rather than a localised one). However, there are still some internal drivers in the system to minimise the impact of farming activities on local resources directly affecting their productivity (see R5 and R6 in **Error! Reference source not found.**).

As the economic benefits of implementing these alternatives might only materialise in the long run, economic feasibility is a big 'limit to success' for these alternatives (see B19 in Figure B9), particularly if consumers are not willing to pay for products that have been produced in more sustainable ways. In practise, some of these alternatives might be unfeasible due to the cost and the lag between investment and return. Social self-organization (see B7 in Figure B5B5), shared learning (see B6 in Figure B5B5) and investment in product valorisation (see R4 in Figure B2) might prove valuable supporting mechanisms to ease these challenges. For instance, farmers' organizations can support their members to get certifications (e.g. organically produced) that consumers value and are willing to pay for.

3.9 Applying the system dynamics model: alternatives for EU farming systems and resilience attributes

The results of using our analysis to explore how the alternative systems explored might affect and might be affected by the resilience attributes identified in SURE-Farm are presented in Table 6. When the resilience attribute contributes or facilitates the development of the system in a particular alternative system, we marked the effect of the attribute on enabling environment as "positive". See for example the attribute "reasonably profitable" and the enabling environment for systems focused on production and economic functions in Table . Conversely, if a resilience distribute might hinder the system development in a particular direction, we marked the effect of the attribute on enabling environment as "negative". There are few examples for negative relationships, but see for instance the attribute "globally autonomous and locally interdependent" and the enabling environment for systems focused production and economic functions in Table 6.

Table 6. Summary of the effects of resilience attributes on the enabling environment where the alternative systems explored are more likely to succeed and the impact of the same alternative systems on such attributes.

	Effect of the attribute on enabling environment			**Effect of alternative systems on the attribute**		
System with a focus on	production and economic functions	social functions	environmental functions	production and economic functions	social functions	environmental functions
Reasonably profitable	Positive	Positive	Positive	Positive	Not conclusive	Not conclusive
Coupled with local and natural capital **(production)**	Not assessed	Positive	Positive	Not assessed	Positive	Positive
Functional diversity	Positive	Positive	Positive	Not conclusive	Positive	Positive
Response diversity	Not assessed	Positive	Positive	Negative	Positive	Positive
Exposed to disturbance	Not assessed	Not assessed	Not assessed	Not assessed	Not assessed	Not assessed
Spatial and temporal heterogeneity **(farm types)**	Not assessed	Positive	Positive	Negative	Positive	Positive
Optimally redundant *(farms)*	Negative	Not assessed	Positive	Negative	Not assessed	Positive
Supports rural life	Not assessed	Positive	Not assessed	Negative	Positive	Not assessed
Socially self-organized	Positive	Positive	Positive	Positive	Positive	Positive
Appropriately connected **with actors outside the farming system**	Not assessed	Not assessed	Not assessed	Not assessed	Not assessed	Not assessed
Coupled with local and natural capital **(legislation)**	Not assessed	Not assessed	Positive	Not assessed	Not assessed	Positive
Infrastructure for innovation	Positive	Positive	Positive	Not assessed	Not assessed	Not assessed
Diverse policies	Not assessed	Not assessed	Not assessed	Not assessed	Not assessed	Not assessed
Ecologically self-regulated	Not assessed	Not assessed	Positive	Not assessed	Not assessed	Positive
Optimally redundant *(crops)*	Not assessed	Not assessed	Positive	Not assessed	Not assessed	Positive
Optimally redundant *(nutrients & water)*	Not assessed	Not assessed	Positive	Not assessed	Not assessed	Positive
Spatial and temporal heterogeneity **(land use)**	Not assessed	Positive	Positive	Negative	Positive	Positive
Optimally redundant *(labour)*	Positive	Not assessed	Not assessed	Not assessed	Not assessed	Not assessed
Globally autonomous and locally interdependent	Negative	Not assessed	Positive	Negative	Not assessed	Not assessed
Reflective and shared learning	Positive	Positive	Not assessed	Not assessed	Not conclusive	Not conclusive
Honours legacy	Negative	Positive	Not assessed	Not assessed	Positive	Not assessed
Builds human capital	Positive	Positive	Positive	Not conclusive	Not conclusive	Not conclusive

Note: Resilience attributes based on Cabell and Oelofse (2012) and adapted in the context of the SURE-Farm project (Paas et al., 2019; Appendix A).

Likewise, we marked as positive those cases when the alternative system will contribute to build a particular resilience attribute. For example, a system with a focus on social functions could be expected to have a "positive" effect on the attribute "supports rural life" (see Table). Contrarily, if an alternative system might erode a resilience attribute, we marked effect of alternative systems on the attribute as "negative". See for example the effect of alternative systems with a focus on production and economic functions on the attribute "response diversity" (see Table).

In some cases, it was not possible to establish a likely relationship between the alterative system and the attribute. In those cases, we marked our results as 'not conclusive' in Table 6. There are several relationships that we could not explore with the conceptual model (blanks in Table). Since the model was built around stakeholders' perspectives, some resilience attributes were outside the boundaries of the model (marked as "not assessed").

As it might be expected, the results presented in Table confirm that there is an alignment between the aims of alternative systems explored and their impact on resilience attributes that are within the same goal. For instance, alternative systems with a focus on improving production and economic functions mainly contribute to build the attribute "reasonably profitable". Similarly, alternative systems with a focus on improving social functions contribute to improve social resilience attributes (see for example "supports rural life", "builds human capital" and increase "reflective and shared learning" in Table 6) and alternative systems with a focus on improving environmental functions will contribute those related with natural capital and ecosystem services ("coupled with local and natural capital" and are "ecologically self-regulated").

The results suggest that some dynamics in the alternative systems might hinder their own development by having negative effects on those resilience attributes that contribute to their enabling environment. For instance, alternative systems with a focus on improving social functions might compromise their profitability in the long-term, making it difficult for farms to provide their desired outcomes (see Table). There are also cases where alternative systems might affect a resilience attribute either way (positively or negatively) but the same attribute was found to contribute in a positive way to the alternative system development (e.g. functional diversity). In the next section we evaluate those cases and the conditions that could favour virtuous loops between the system and attributes.

3.10 Interpreting the system dynamics model: synergies and trade-offs between attributes

Analysing the conceptual model, we found that stakeholder perception regarding a strong correlation between "reasonably profitable" and other resilience attributes is justified. Economic viability is also instrumental to all the strategies needed to reach any of the proposed alternative systems (see Figure 8).

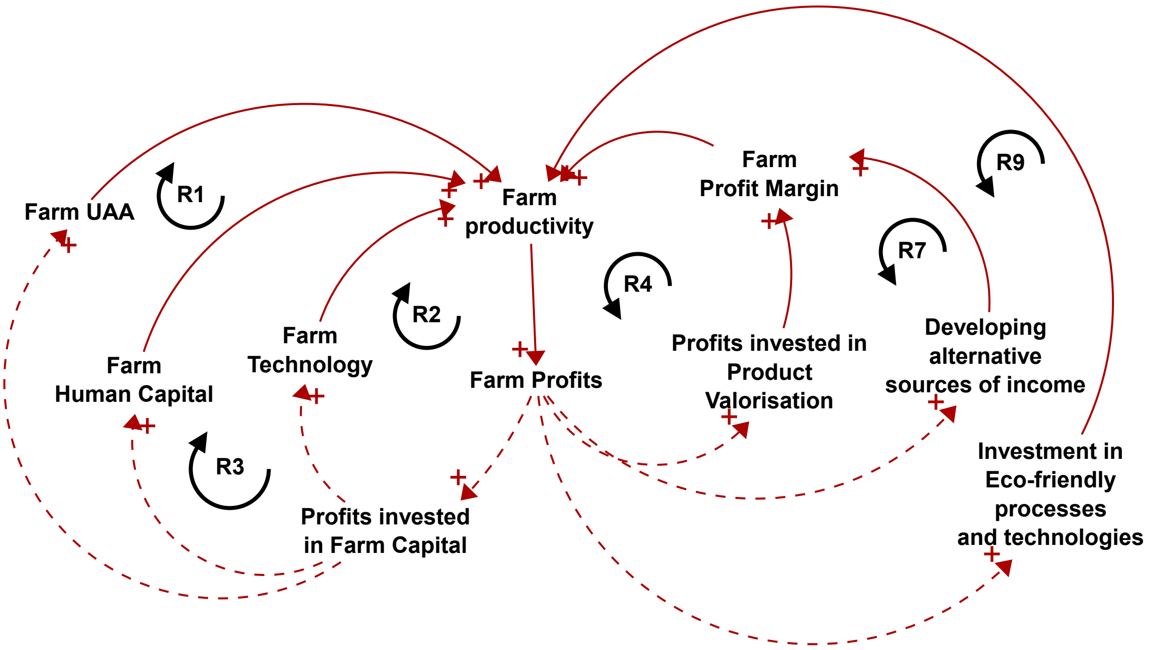

Figure 8. Competing potential configurations for increasing farmers' utility

Hence, a big challenge for alternative systems with a focus on social and environmental functions is to still be relatively profitable while focusing on delivering a wide range of societal needs. If increasing their profitability remains among farmers' priorities, the 'success to the successful mechanism' (see Figure 8) is likely to justify the allocation of more economic resources to those strategies that deliver better economic performance. In these conditions, it will be challenging to implement alternative systems with wider aims without external interventions (e.g. subsidies, legislation).

In Appendix B we argue that there are mechanisms in the system that can make alternative systems with a focus on social and environmental functions relatively profitable without shifting their focus towards economic goals. For instance, farmers can diversify their sources of income (B6 in Figure) and identify ways to commercialise other functions that benefit from their strategies, for example by developing agritourism (Bitsani and Kavoura, 2012). Social self-organization is another important leverage mechanism to increase the feasibility of alternative systems and their resilience. Cooperatives and other forms of social self-organization can improve the chances of success for majority of strategies.

3.10.1 Synergies and conflicts between specialisation and diversification

In our analysis we associated functional diversity with alternative sources of income and did not explore non-economic benefits from functional diversity (e.g. cultural landscape, recreation, and climate change mitigation). Since we only looked at functional diversity and its contribution to farm profits, alternative systems with a focus on improving production and economic functions could expect to benefit from 'functional diversity', and higher profits in the same systems enable investment in diversification strategies. This virtuous cycle was represented in R9 in the conceptual model (see Figure 8).

If farmers invest in developing alternative sources of income, the alternative systems with a focus on production and economic functions are likely to have a positive impact on increasing functional diversity. Functional diversity can mitigate risks associated with other characteristics of these alternative systems as it can reduce the impact of oscillations in the market, bad yields, and other unexpected shocks (Darnhofer et al., 2010a).

However, the impact of these systems is not necessarily positive. First, as shown in B6 Figure , higher profits reduce the incentives for diversification and finding alternative sources of income. This combined with farmers' conservative attitudes is likely to make them less interested in exploring new income sources. Second, technical specialisation is also likely to reduce farmers' openness to try alternative sources of revenue (Giller et al., 1997). If the technologies used for mechanising the system are too specialised, it might be too difficult or too expensive for farmers to diversify. The effect of these two loops (B6 and B20 in Figure 9) is likely to swing the system away from functional diversity.

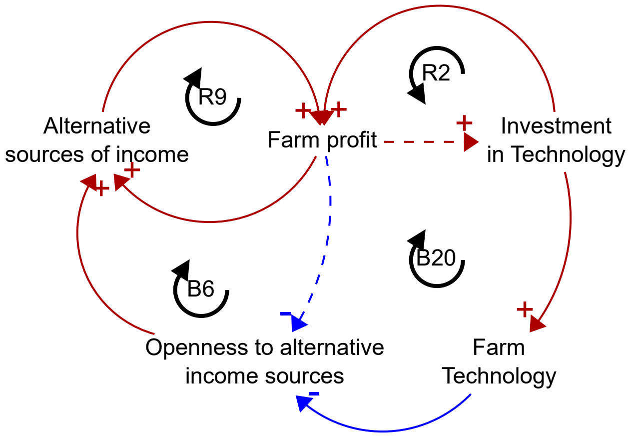

Figure 9. A causal loop diagram showing some dynamics affecting functional diversity.

3.10.2 Synergies of social self-organization

In general, all alternative systems benefit from an environment that facilitates and encourages self-organization among farmers. Social self-organization is often mentioned in the literature as an important attribute for building human capital and facilitating learning. For instance, social self-organization can provide a space for learning and cooperation that will naturally foster the development of know-how and human capital in the system (Darnhofer et al., 2010a). Hence, the positive synergies between social self-organization and alternative systems with a focus on social functions does not come as a surprise.

However, the benefits of social self-organization might go beyond social functions and, for example, increase farmers' bargaining power facilitating product valorisation potentially boosting prices and profits (see B7 in Figure B5). In alternative systems with a focus on production and economic functions, social self-organization might play an important role in product valorisation (Ilbery and Kneafsey, 1999) increasing farmers' leverage in increasingly competitive environments (B7 in Figure). Higher profits facilitate the constitution of a good environment for developing human capital, creating reasonably well paid jobs and offer good working conditions (Šūmane et al., 2018). As social self-organization has a positive effect on learning sharing and human capital development, social self-organization might be a key vehicle for these alternative systems to deliver some societal functions that otherwise would be neglected.

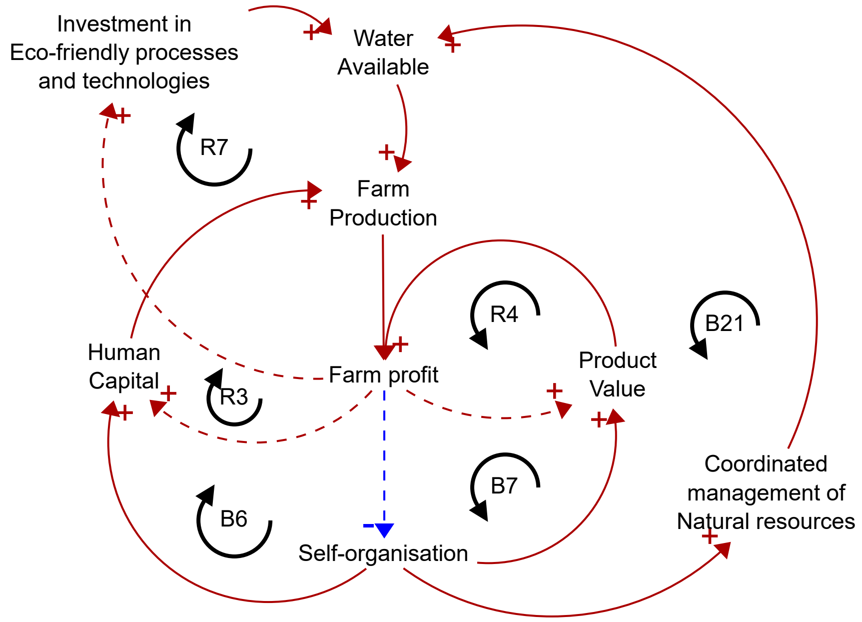

Figure 10. A causal loop diagram showing effects of social self-organization on alternative systems strategies.

Similarly, social self-organization can help farmers in alternative systems with a focus on environmental functions to differentiate their products (Beuchelt and Zeller, 2013; Brouwer et al., 2018; Oehen et al., 2018). This differentiation might help farmers to pay for the additional costs resulting from implementing eco-friendly practices. Farmers' organization might be instrumental in implementing strategies within these alternative systems because some natural resources (e.g.

water, pollinators, or biodiversity) are not bounded to a farm but are shared by many. Hence, the success managing these resources depends on cooperation between all those that use and affect the natural resources in the area (Kulkarni and Tyagi, 2012; Renting and Van Der Ploeg, 2001). Coordinating management of natural resources (particularly water) is likely to benefit the environment and improve farm productivity (see B21 in Figure), enabling farmers to invest more in eco-friendly practices that reduce water consumption (see R7 in Figure).

3.10.3 Synergies and caveats of human capital

Human capital and farmers' know-how are important contributors to farm productivity and key enablers for diverse responses and resilience. As with systems with a focus on social self-organization, developing human capital has the potential to deliver economic benefits that are needed to implement any of the alternative systems explored. The potential contribution of human capital towards farm productivity and its synergies with other attributes, makes it likely that any of these systems will contribute to build human capital to some extent.

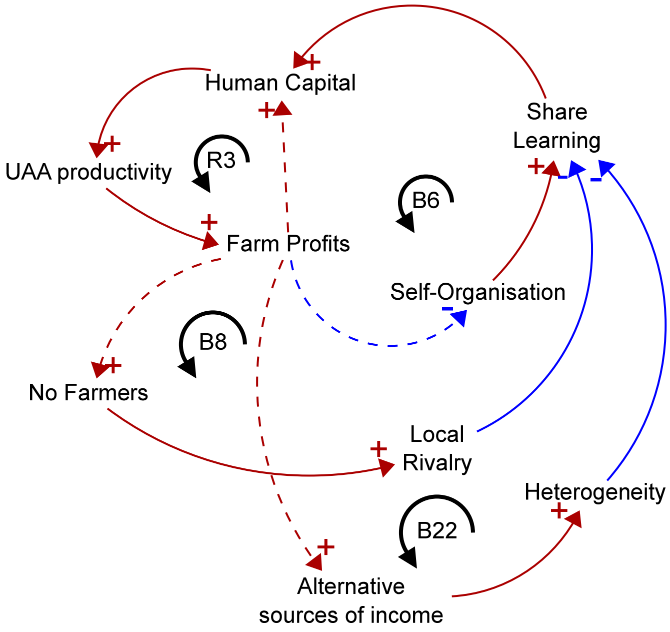

Figure11. A causal loop diagram showing dynamics influencing shared learning and human capital in farming systems.

However, in our analysis we found that "shared learning" and the development of human capital might be hindered in those alternative systems where local rivalry between farmers is more likely (Cleary et al., 2019; Kuimov et al., 2018). For instance, shared learning is likely to be difficult in systems where farms concentrate in local markets, because this system can expect higher competition between neighbours for both inputs and consumers (see B8 in Figure). Likewise, shared learning might be difficult in more heterogeneous systems with larger numbers of farmers that have little in common (see B22 in Figure1).

Since heterogeneity and a focus on local markets are characteristics of alternative systems focusing on improving social and environmental functions, these systems might struggle to keep developing human capital without external institutional support. Strategies focusing on improving social functions should be particularly mindful of these challenges as they rely on human capital as main driver for economic viability.

3.10.4 Enabling environment for different alternative systems

Overall, our results suggest that the alternative systems proposed by stakeholders benefit of an environment that encourages and facilitates farmers economic performance, social self-organization, and functional diversity. While we have not been able to assess all the resilience attributes using system dynamics, looking at these three and some of the other resilience attributes that are expected to have a positive impact on the alternative systems, we can start to elaborate on how such enabling environment might look like. Depending on which functions are considered most important, are closest to critical thresholds and therefore require most improvements, different type of strategies require more attention in the short-term.

Alternative systems with a focus on production and economic functions benefit from environments that reduce financial risks and exposure to price volatility. Since these systems are likely to be relatively homogeneous and reliant on global markets, competition and market risks are likely to be high. In this context it is unlikely that diversification and social self-organization will flourish. Strategies that improve farmers' access to insurance packages, reliable high-quality inputs (e.g. labour) and to diverse and robust markets might be good for these systems. The 'limits to success' should be recognized early on, by timely unlocking other loops with different strategies (see Appendix B). The focus on production and economic functions has a negative effect on many resilience attributes (Table 6), while in the long-term all resilience attributes are important to build resilience.

Alternative systems with a focus on improving social functions benefit from environments that contribute to the development of human capital with institutional support that facilitates cooperation among farmers and creates interdependencies between neighbours. In particular, these systems might benefit from institutions that can help them to coordinate their efforts, create safe spaces for shared learning and help farming system actors to find common goals.

Alternative systems with a focus on improving environmental functions benefit from environments with high and consistent environmental awareness and institutional support for cooperation. For example, these systems are likely to be more profitable in environments where all farmers must comply with similar environmental standards, either because it is required by the legislation or because it is demanded from the consumers. The drivers for such environment are, at least partially, beyond the boundaries of the farming system. Like alternative systems with a focus on improving social functions, those with a focus on environmental functions will need support to coordinate their efforts in a heterogenous landscape.

4 Discussion

4.1 Contribution of strategies to sustainability and resilience

The main aim of this report was to assess the impact of past and future strategies on sustainability and resilience, in order to inform farming system stakeholders on interventions required. Inputs from participatory assessments, subsequent interpretations by researchers and system dynamics modelling were used. In order to assess impacts on sustainability, the delivery of private and public goods was represented by eight system functions based on Meuwissen et al. (2019). In order to assess impacts on resilience, contributions of strategies to 22 resilience attributes were considered (based on Paas et al., 2019).

Results showed that when maintaining status quo, specifically the functions “economic viability”, “attractiveness of the area” and “quality of life” were at risk, and that there were interacting thresholds. Also resilience attributes “reasonably profitable” and “appropriately connected with actors outside of the system” were expected to develop negatively, which is related to function performance. In order to improve these and other functions and attributes, alternative systems with associated strategies were proposed by stakeholders. Proposed alternative systems paid specific attention to the declining functions, but also to improve “biodiversity and habitat”. While in some case studies, it was argued that different alternatives could be combined, in others they went in different directions, with opposite impacts on social and environmental functions.

With regard to resilience-enhancing attributes, strategies in the past specifically enhanced “reasonably profitable”, “builds human capital”, “socially self-organized”, “infrastructure for innovation”, “response diversity”, “functional diversity” and “production coupled with local and natural capital”. Strategies implemented in the past however allowed main indicators to remain robust, but overall resilience was judged to be low (Paas et al., 2019; Reidsma et al., 2020). When identifying strategies that are needed to reach alternative systems, there was relatively most focus on strengthening “coupled with local and natural capital”, both regarding production and legislation. The increased focus on strengthening “diverse policies”, “coupled with local and natural capital (legislation)” “appropriately connected with actors outside of the farming system”, "coupled with local and natural capital (production)", "functional diversity" and "ecologically self-regulated" suggests that in the future more attention is needed for an enabling institutional environment, and also for attributes strengthening ecological processes.

The SD modelling confirmed the importance of the main attributes, specifically "reasonably profitable" and "socially self-organized", and giving more emphasis to the role of "functional diversity". The SD model also explained why specifically alternative systems focusing on economic and production functions may have a negative impact on certain resilience attributes. However, as such systems are expected to have a positive impact on being "reasonably profitable" in the short-term, and this is uncertain for systems focusing on social and/or environmental functions, as long as "limits to success" are not reached, stakeholders perceive systems focusing on economic and production functions as desirable directions.

In FoPIA-SURE-Farm 1, stakeholders perceived "infrastructure for innovation" to be particularly important for transformability (Paas et al., 2019; Reidsma et al. 2020). While governments need to contribute to transformability by developing long-term visions and continuous and improved legislation, it has been suggested that the role of governments in investments and risk-management is crucial (Mazzucato, 2018). Governments need to ensure "infrastructure for innovation" by developing "diverse policies" (with less focus on robustness, and more on transformability), and investing in risky strategies to make alternative directions "reasonably profitable". The EU Rural Development Programmes (RDP) are good examples; in NL-Arable for example, these subsidies stimulate innovation, and also allow to be "appropriately connected with actors outside the farming system" (see https://www.pop3subsidie.nl/blog/kennisbank/veenkolonien-samenwerking-voor-innovaties/; in Dutch).

4.2 Is the list of resilience attributes complete?

Resilience attributes considered were based on Cabell and Oelofse (2012), and adapted in the context of the SURE-Farm project (Paas et al., 2019; Appendix A). "Infrastructure for innovation" and "Support rural life" were added, and several attributes were split and adapted to make them more specific for farming systems. The list of 22 attributes was however too long to discuss with stakeholders, and therefore only the main 13 were assessed during the FoPIA-SURE-Farm 1 workshops (Paas et al., 2019; Nera et al., 2020; Reidsma et al., 2020). Some of the omitted attributes were nevertheless specifically emphasized to be important for resilience by other authors like Tittonell (2020), including "ecologically self-regulated", "reflective and shared learning", and "builds human capital". On the other hand, Tittonell (2020) omitted "reasonably profitable" from his main list, while this attribute appeared to be the most important according to our assessments.

We evaluated to what extent the 13 attributes discussed in FoPIA-SURE-Farm 1 were sufficiently covering resilience. An association matrix was made to assess to what extent strategies that enhance one attribute also enhance other attributes. Table D1 shows that there is indeed overlap, as for example, most strategies that contribute to "ecological self-regulated" also contribute to "coupled with local and natural capital (production)"; however, the opposite is much less the case. The same is true for "builds human capital" and "reflective and shared learning" when compared to "social self-organization"; here the opposite is also the case. Synergies between these attributes were also explained with the SD model. Hence, whereas adding the last 9 attributes does provide additional information, and allows comparison with earlier studies, this association matrix confirms that using the selected 13 attributes for a participatory assessment was largely sufficient for a holistic overview of resilience.

Nevertheless, some other attributes could be added. As also argued by Paas et al. (2020) an attribute specifically targeted to experimentation could be useful. As alternative systems that aim to improve social and environmental functions are not necessarily profitable, and new business models need to be developed, experimentation is needed. It can be argued that this is covered by "infrastructure for innovation", "social self-organization" and "shared and reflective learning", but it may not get the attention when not specifically emphasized. Further, Walker & Salt (2012) also mention "equity" relating to equality and a sense of agency among people. Our results show that different types of actors are needed, and hence, such a resilience attribute would allow to roughly assess whether stakes among stakeholders are aligned. From a specified resilience point of view, this relates to the question "resilience for whom?". Another attribute mentioned by Walker & Salt (2012) is "humility", relating to the acknowledgment that in the end we are dependent on ecological processes for survival. Via the specified resilience route (resilience of what, to what, for what?) we already discovered that this acknowledgment is in most case studies low. Our assessment showed that being "reasonably profitable" is needed in the first place for farming systems to be resilient, but in the long-term this is not sufficient.

While the number of resilience attributes that need to be considered may be enlarged or reduced, resilience attributes are suggested to be synergistic in nature, implying positive interactions (e.g., Nemec et al., 2014; Walker and Salt, 2012) or even purposely reinforcing processes (Bennett et al., 2005). The SD model also confirmed the positive interactions between several resilience attributes, but also emphasized possible negative interactions between "reasonably profitable" and other attributes (Section 3.10). Under influence of the current institutional environment and/or current socio-technological regime with a focus on production and economic functions, synergistic effects seem to be diminished, which results in a one-sided approach to resilience. A strong focus on agro-ecological transition of farming systems on the other hand (e.g. Tittonell, 2020), may result in an overemphasis on diversity and redundancy, neglecting the importance of economic viability. Synergistic effects imply co-evolution. However, to realize resilience attributes, claims on the same resources might be made. At the same time, resilience attributes may ensure the availability of resources in the long term.

Both Cabell and Oelofse (2021) and Tittonell (2020) also related attributes to phases in the adaptive cycle, based on literature (see Figure 12). The strong point of the participatory assessments in SURE-Farm, is that they provide a good basis for understanding the importance of resilience attributes for different resilience capacities, which relate to the adaptive cycle. Reidsma et al. (2020) showed that specifically “reasonably profitable”, “production coupled with local and natural capital”, “socially self-organized” and “infrastructure for innovation” were assessed to be important for robustness and adaptability, while the latter was also emphasized for transformability. Cabell and Oelofse (2012) and Tittonell (2020) related “reasonably profitable” to the conservation phase (where mainly robustness is important), “socially self-organized” and “production coupled with local and natural capital” to the reorganization to exploitation phase (where mainly transformability is important), whereas “infrastructure for innovation” was not considered. Other attributes that were largely strengthened by identified strategies (this report) were suggested to be mainly relevant for reorganization (“reflective and shared learning”, “legislation coupled to local and natural capital”) or throughout (“builds human capital”, “functional diversity”) (Cabell and Oelofse, 2012; Tittonell, 2020). In FoPIA-SURE-Farm 1, the importance of “functional diversity” was confirmed by relatively high and similar scores for robustness, adaptability and transformability.

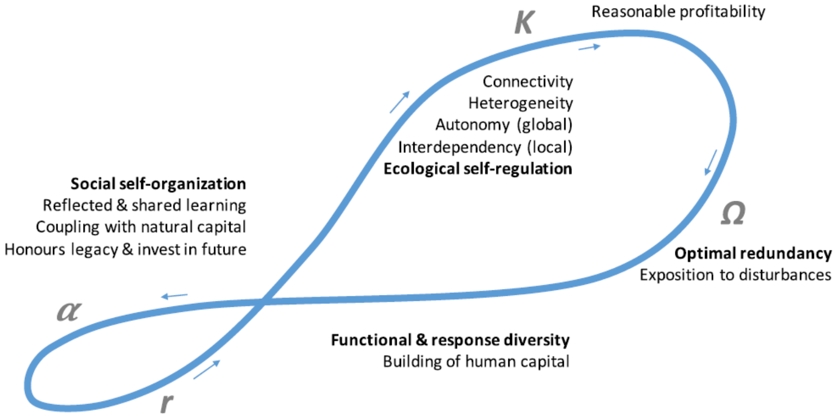

Figure 12. The ´tilted´ adaptive cycle and the most relevant indicators of resilience and adaptability (following Cabell and Oelofse, 2012) associated with each phase of the cycle. Functional and response diversity, as well as building of human capital, are relevant throughout the cycle (Source: Tittonell, 2020). Note that this figure does not reflect our results, but is used as basis for discussion.

Based on our assessments, we can conclude that "reasonably profitable" is more important than suggested in earlier literature. This was also confirmed by the focus groups on risk management (Soriano et al., 2020). In order to develop farming systems that can improve the delivery of private and public functions, and remain resilient in the long-term, being economically viable is a prerequisite. Hence, business models need to be developed that allow the development of alternative systems. Experimentation and learning need to be supported by actors in and outside the system to reduce risks (Soriano et al., 2020) and "to anticipate change and create desirable futures" (Cabell & Oelofse, 2012). Especially experimentation is dependent on financial surpluses and hence the resilience attribute "reasonable profitable" (Paas et al., 2020). We can also conclude that the emphasis regarding strategies so far is on conservation (robustness), but that there is attention for reorganization and exploitation (growth). However, strategies specifically identified for alternative systems switch focus from the conservation phase to a focus on moving from reorganization to exploitation, and consequently moving from exploitation to conservation (e.g. "diverse policies", "appropriately connected with actors outside of the farming system", "ecologically self-regulated"). It should be noted, however, that while the contribution to these attributes potentially enhances resilience, stakeholders in FoPIA-SURE-Farm 1 were not convinced on the positive impacts on resilience capacities (Reidsma et al., 2020). Strengthening single attributes will not enhance resilience, but attention for all is required simultaneously, at least in the long-term.

4.3 Triangulation of methods

As mentioned in section 2.1, qualitative approaches to understand resilience are promoted (e.g. Darnhofer et al., 2010; Cabell and Oelofse, 2012; Darnhofer, 2014; Walker et al. 2002; Ashkenazy et al. 2018; Payne et al. 2018; Sellberg et al. 2017). However, participatory approaches have their caveats. Participatory exercises are strongly influenced by existing social relationships, and information is shaped by relations of power and gender, and by the investigators themselves (Mosse, 1994). Therefore, it has been suggested that participatory assessments need to be complemented by other methods of 'participation' which generate the changed awareness and new ways of knowing, which are necessary to locally-controlled innovation and change (Mosse, 1994). Participatory approaches do not allow to understand individual thoughts, feelings, or experiences (Hollander, 2004) and need to be complemented by interviews with individuals to generate meaningful results. For this reason, SURE-Farm applied a range of qualitative and quantitative approaches to improve understanding of sustainability and resilience in 11 EU farming systems (Meuwissen et al., 2019; Reidsma et al., 2019; Accatino et al., 2020). Whereas the current assessment was mainly based on FoPIA-SURE-Farm 1 and 2 to ensure consistency, these methods were complemented with other methods and triangulation took place to assess consistency of results. Using SD we combined stakeholders' perspectives with theories and empirical evidence found in the literature and checked the coherency of perspectives by looking at them from a system perspective. Further, different groups of stakeholders were consulted in each case study, and the comparison of results across case studies averaged out opinions of individuals or case study specific results. In addition, the FoPIA-SURE-Farm approach itself did not solely rely on group discussions, but also included individual assignments in order to collect knowledge and perceptions of individuals. Lastly, part of the work (section 3.5-3.7) was executed by case study researchers, to ensure good understanding of the concepts.

Mosse (1994) argued that what is often missing in the employment of participatory methods, is an assessment of the limits of local knowledge and awareness, and the constraints to existing community systems of problem solving. This caveat was specifically addressed by assessing which farming system functions and resilience attributes were less considered by stakeholders, and by complementing the assessment with system dynamics modelling. Applying the framework of Kinzig et al. (2006) with interacting thresholds across domains and scales is a good starting point for identifying the limits of knowledge, especially with regard to system functions. With regard to resilience attributes, the identification of alternative systems and strategies showed that attention for the resilience principles diversity and redundancy was lacking. Hence, more attention is needed for interventions that can enhance attributes related to these. Moreover, as highlighted by the SD analysis, the interaction between alternative systems and resilience attributes needs further consideration. Decisions based on short term goals might erode future resilience by limiting the potential configurations the system might take. In this sense, the analysis suggests that there is a potential conflict between short- and long-term resilience and in the long-term a balanced attention for all dimensions is needed.

5 Conclusion

The main aim of this report was to identify past and future strategies in farming systems across the EU, to assess how these contribute to the delivery of private and public goods and resilience-enhancing attributes, and to identify additional interventions needed by farming system actors and the enabling environment.

Stakeholder and expert assessments were used, and underpinned by system dynamic modelling. This allows an integrated assessment, addressing the whole farming system and all challenges, system functions and resilience attributes. Additional quantitative approaches are needed to provide hard evidence.

Strategies implemented in the past mainly aimed to strengthen the resilience-enhancing attribute “reasonably profitable”, followed by “builds human capital”, “socially self-organized”, “infrastructure for innovation”, “response diversity”, “functional diversity” and “coupled with local and natural capital (production)”. Strategies in the past were however perceived to improve the robustness of main indicators, but overall resilience of farming systems was judged to be low. Maintaining status quo was also judged to lead to a decline in the delivery of private and public goods and resilience attributes. When identifying strategies that are needed to reach alternative systems, which do have the potential to improve the delivery of private and public goods, there was relatively most focus on strengthening “coupled with local and natural capital”, both regarding production and legislation. Such strategies include improving soil quality, using varieties adapted to local climatic conditions, reducing inputs, improving circularity, local branding, and policies that support this. The increased focus on strengthening “diverse policies”, “coupled with local and natural capital (legislation)”, “appropriately connected with actors outside of the farming system”, “coupled with local and natural capital (production)”, “functional diversity” and “ecologically self-regulated” suggests that in the future more attention is needed for an enabling institutional environment, and also for attributes strengthening ecological processes.

Alternative systems identified by stakeholders can be considered as possible directions for the future, aimed at improving main system functions and resilience attributes. Most alternatives were however adaptations, not transformations of current systems. While in some case studies, different alternatives were compatible, in others they moved in different directions. Systems dynamics (SD) modelling was used to further explore the dynamics in the proposed alternative systems by grouping them into systems that mainly improve 1) production and economic, 2) social or 3) environmental functions. The results suggest that the alternative systems proposed by stakeholders specifically benefit from an environment that encourages and facilitates farmers' economic performance, social self-organization, and functional diversity. SD modelling also highlighted the importance to take a dynamic perspective and to consider how current responses and decisions affect long term resilience. Systems focused on production and economic functions may seem to enhance resilience in the short-term, but as these negatively affect many resilience attributes, in the long-term resilience may deteriorate, as there are ‘limits to success’. The SD model shows that these limits to success are on the one hand determined by the potential degree into which a resource can effectively be turned into a desired good, and on the other hand determined by environmental and social feedback loops that need to be nurtured in order to sustain economic feedback loops. The SD model thus provides a strong suggestion for a balanced attention for economic, social and environmental dimensions

Different alternative systems will thrive under different enabling environments, and therefore all may be feasible options, but this depends on future scenarios. When assessing the compatibility of the status quo and suggested alternative systems with the five Shared Socio-economic Pathways for European agriculture and food systems (Eur-Agri-SSPs), it was concluded that most alternatives mainly thrive in the scenario ‘agriculture on sustainable paths’, while being specifically vulnerable in ‘agriculture on separated paths’. Therefore, flexibility is required to adjust the strategies according to the nature of future conditions. As also emphasized by the SD modelling, resources can only be spent once, and focusing on one direction may limit options on the future.

While current strategies are often aimed at improving one function (e.g. “economically viable”) and/or resilience-enhancing attribute (e.g. “reasonably profitable”), sustainability and resilience can be improved when (a combination of) strategies improve multiple functions and attributes at once. All actors in the farming systems need to collaborate in order to make a change.

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7 Appendix A. Resilience attributes

In FoPIA-SURE-Farm 1 (Paas et al., 2019) the list with original attributes as proposed by Cabell & Oelofse (2012) was extended by splitting up original attributes (italic in Table A1) and adding new attributes and explanations (bold in Table A1) based on the research focus and the resilience research framework of SURE-Farm (Meuwissen et al. 2019). For the sake of workability during the FoPIA-SURE-Farm 1 workshops, only 13 attributes were selected to be evaluated in the workshops (in green). The other 9 were also considered when assessing the contribution of strategies to attributes.

Table A1 . Attribute list based on Cabell & Oelofse (2012) and Meuwissen et al. (2019). Italic font indicates that these attributes are split up with reference to the original attribute in Cabell & Oelofse (2012). Bold font indicates that the information is based on Meuwissen et al. (2019). Green font indicates that these attributes are selected to be evaluated during the FoPIA-SURE-Farm 1 workshops. Source: Paas et al. (2019).

Resilience attribute	**Definition**	**Implications**	**Characteristics**	**Related to SURE-Farm process**	**Related to general resilience attributes**
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; agriculture sector does not rely on distortionary subsidies	Agricultural production	System reserves
Coupled with local and natural capital **(production)**	The system functions as much as possible within the means of the bioregionally 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	Builds or maintains soil fertility, recharges water resources, little need to import nutrients or export waste	Agricultural production	System reserves
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*	*Diversity of inputs, outputs, income sources, markets, etc.*	*Risk management*	*Diversity*

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*	***Diversity of risk management strategies****, e.g. different pest controls,* ***weather insurance, flexible payment arrangements.***	*Risk management*	*Diversity*
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”	Pest management that allows a certain controlled amount of invasion followed by selection of plants that fared well and exhibit signs of resistance	Risk management	Openness
Spatial and temporal heterogeneity **(farm types)**	Patchiness across the landscape and changes through time	Like diversity, spatial heterogeneity provides seeds of renewal following disturbance	**Diverse farm types with regard to economic size, intensity, orientation and degree of specialisation.**	**Farm demographics, risk management**	**Modularity, diversity**
Optimally redundant ***(farms)***	*Critical components and relationships within the system are duplicated in case of failure*	*Also called response diversity; 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 stop without endangering continuation of the farming system and new farmers can enter the farming system easily***	***Farm demographics; risk management***	***Modularity***
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.**	**A balanced population with young, intermediate and older people; Enough facilities in the nearby area to maintain an adequate standard of life.**	**Farm demographics**	**System reserves**
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, farmer’s markets, community sustainability associations, and advisory networks	Governance	Tightness of feedbacks

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 level**	Governance	Tightness of feedbacks
Coupled with local and natural capital **(legislation)**	**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 framework adapted to the local conditions**	**Governance, agricultural production**	**System reserves**
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.**	**Infrastructure that allows new ways of agricultural production and improved information flows e.g. allowing track and trace of agricultural products throughout the value chain.**	**Governance, agricultural production**	**Openness, system reserves**
Diverse policies	**Policies stimulate all three capacities of resilience, i.e. robustness, adaptability, transformability**	**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 that create a stable and safe environment in which experimentation and structural change for more sustainable agriculture is supported.**	**Governance**	**Diversity**
Ecologically self-regulated	Ecological components selfregulate via stabilizing feedback mechanisms that send information back to the controlling elements	A greater degree of ecological self-regulation can reduce the amount of external inputs required to maintain a system, such as nutrients, water, and energy	Farms maintain plant cover and incorporate more perennials, provide habitat for predators and parasitoids, use ecosystem engineers, and align production with local ecological parameters	Agricultural production	Tightness of feedbacks

Optimally redundant ***(crops)***	*Critical components and relationships within the system are duplicated in case of failure*	*Also called response diversity; 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*	*Planting multiple varieties per crop rather than one, keeping equipment for various crops*	*Risk management*	*Modularity*
Optimally redundant ***(nutrients& water)***	*Critical components and relationships within the system are duplicated in case of failure*	*Also called response diversity; 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*	*Getting nutrients and water from multiple sources.*	*Risk management*	*Modularity*
Spatial and temporal heterogeneity **(land use)**	Patchiness across the landscape and changes through time	Like diversity, spatial heterogeneity provides seeds of renewal following disturbance; through time, it allows patches to recover and restore nutrients	Diverse land use on the farm and across the landscape, mosaic pattern of managed and unmanaged land, diverse cultivation practices, crop rotations	Risk management	*Modularity, diversity*
Optimally redundant ***(labour)***	*Critical components and relationships within the system are duplicated in case of failure*	*Also called response diversity; 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*	***Labour comes from multiple sources***	***Risk management; Farm demographics***	***Modularity***
Globally autonomous and locally interdependent	The farming system has relative autonomy from exogenous control and influences and inhibits a high level of cooperation between individuals and institutions at the more local level	A system cannot be entirely autonomous but it can strive to be less vulnerable to forces that are outside its control; local interdependence can facilitate this by encouraging collaboration and cooperation rather than competition.	Less reliance on commodity markets and reduced external inputs; more sales to local markets, reliance on local resources; existence of farmer co-ops, close relationships between producer and consumer, and shared resources such as equipment	Governance, risk management	Openness

Reflective and shared learning	Individuals and institutions learn from past experiences and present experimentation to anticipate change and create desirable futures	The more people and institutions can learn from the past and from each other, and share that knowledge, the more capable the system is of adaptation and transformation, in other words, more resilient.	Extension and advisory services for farmers; collaboration between universities, research centers, and farmers; cooperation and knowledge sharing between farmers; record keeping; baseline knowledge about the state of the agroecosystem	Governance	Openness
Honours legacy	The current configuration and future trajectories of systems are influenced and informed by past conditions and experiences	Also known as path dependency, this relates to the biological and cultural memory embodied in a system and its components	Maintenance of old varieties and engagement of elders, incorporation of traditional cultivation techniques with modern knowledge	Governance	System reserves
Builds human capital	The farming system takes advantage of and builds resources that can be mobilized through social relationships and membership in social networks	Human capital includes: constructed (economic activity, technology, infrastructure), cultural (individual skills and abilities), social (social organizations, norms, formal and informal networks)	Investment in infrastructure and institutions for the education of children and adults, support for social events in farming communities, programs for preservation of local knowledge	Governance	System reserves

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8 Appendix B. A conceptual system dynamics model of EU farming systems

In this Appendix B, we describe the conceptual model developed for the farming systems assessed in SURE-Farm. We do this by dividing the model into understandable sections that describe some of the causal relationships influencing farmers' decisions. It is worth noticing that for simplicity, the relationships in the conceptual model are presented at a very aggregated level so that it is possible to see the big picture. The actual model might be more complex than the diagrams presented.

There are a variety of factors that play into the managerial decision farmers to improve their utility. The model does not cover all of them in an exhaustive way. Although feedback loop relationships are shown in separate diagrams, the system performance depends on the simultaneous effect of all them (those included in the model and some that are not). Making conclusions about the system behaviour only based on a single part of the model will be misleading.

8.1 The drivers of production

We start our description of the model by focusing on some of the decisions that farmers can make to increase farm production. Farm production is a function of inputs (water, energy, nutrients, etc.) and different forms of farm capital such as farm cultivated area, farm-specific human capital, physical capital, and technological capital (Lagerkvist et al., 2006; Ahituv and Kimhi, 2002).

In this section we focus on three of the farmers' decisions that might contribute to increase farm capital:

i) increasing farm cultivated area
ii) investing in technology
iii) investing in human capital

These decisions link back to the core structure presented in Figure 3 (methods in section 2.4), where the first decision directly affects the UAA (extensification) and the other two decisions might have a positive effect on UAA productivity (intensification).

Since farmers' ability and willingness to implement such decisions is influenced by their income (McCann, 1997; Knowler and Bradshaw, 2007), decisions aiming to increase farm capital might exhibit a virtuous cycle as the ones shown in Figure B1. For instance, it could be expected that larger farms will result in higher throughputs (farm production) and higher profits than otherwise (see R1 in Figure B1). Higher 'farm profits' eventually results in farmers having more resources available for investing either in continuing to increase their size or in other strategies like investment in technology (R2 in Figure B1) and development of human capital (R3 in Figure 1). These strategies might also contribute towards higher profits contributing towards this reinforcing cycle (see Figure B1). In the past, these cycles resulting in economies of scale in the production, harvesting and processing have contributed to a trend towards specialisation, mechanisation and intensification (Bowman and Zilberman, 2013; Paul et al., 2004).

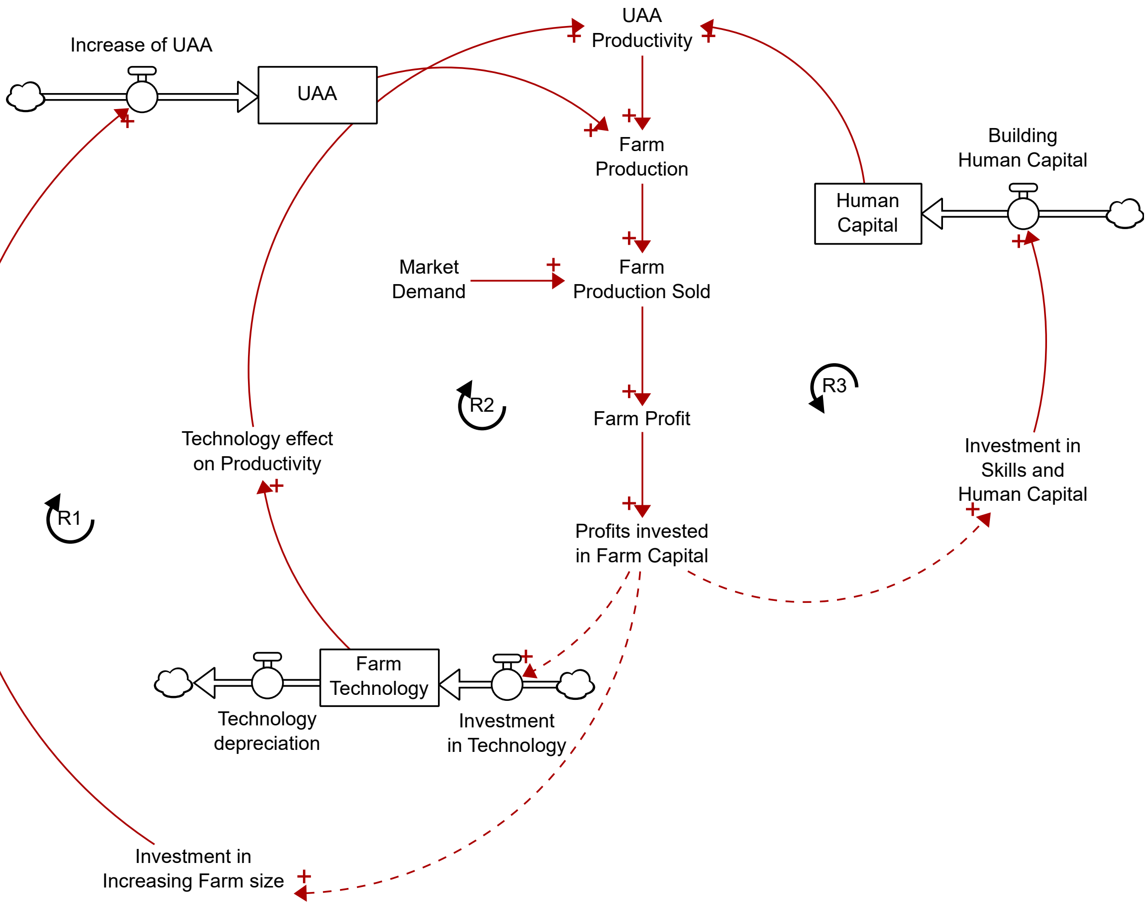

Figure B1. A stock and flow diagram showing system mechanisms that are involved in developing farm capital.

Please note that dotted lines in the diagram (see Figure B1) represent farmers' decision rather than a causal relationship. In practice, farmers attitudes, market conditions, resource availability, risk appetite, concerns for the natural environment and resource availability might prevent them from making such decisions (Bowman and Zilberman, 2013, McCann 1997).

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8.2 Market mechanisms

Market conditions can shape farmers' decisions in many ways. Output conditions like prices, price variability and demand and supply chain costs have significant effects on farm profits and, therefore, on their ability to increase their production. For instance, higher production (supply) leads to lower prices than otherwise. Lower prices result in lower profit, discouraging and limiting farmers' ability to continue increasing their capital (see B1 in Figure B2). Simultaneously, lower prices might be expected to make products more affordable, increasing the demand until the market reaches a new equilibrium between supply and demand (see B2 in Figure B2).

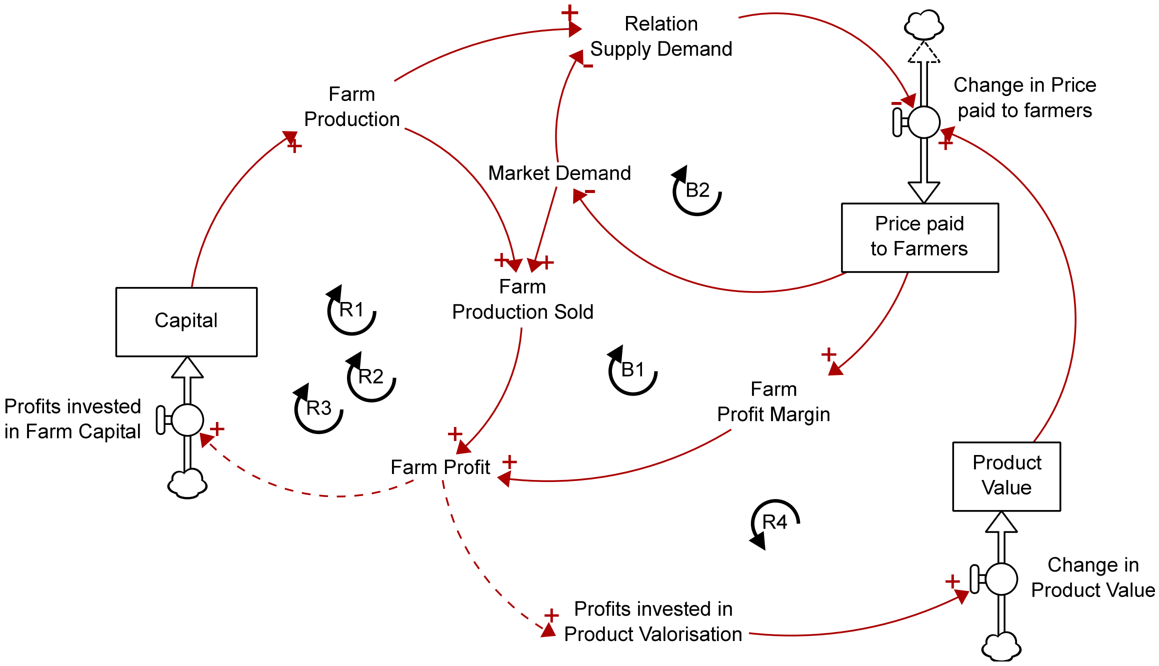

Figure B2. A stock and flow diagram showing market dynamics influencing farming systems profits.

As response to the limits imposed by the market and the price variability, farmers can invest in valorising their products in order to increase the added value and differentiate them from the competitors. This product valorisation can take different shapes. For instance, it can create a competitive differentiator based on the region's heritage or attractiveness (Sgroi et al., 2014; Bessière, 1998). Alternatively, farmers might use vertical integration to increase the value added and the margins perceived (Sacchi et al., 2019). In the conceptual model, we did not consider the details of valorisation and represent it in an aggregated way as shown in R4 (Figure).

8.3 Interactions with local and natural capital

Another factor to consider are the biological and geophysical components of the system that influence "farm production". For instance, water scarcity, soil degradation, climate conditions (e.g. frosts, floods) and pest infestations are environmental factors that diminish farm production (Leemans and Born 1994). As with the market factors, we use the model to explore feedback loop relationships between farming systems and the environment and how the system affects and is affected by the natural environment (Stoate et al., 2001).

In the conceptual model we focus on two natural resources: water and soil organic matter. Water quality and quantity have a direct effect on farming systems' production and water availability is already a concern for farmers (Falloon and Betts, 2010). Farming systems consume water for their production, but mismanagement of water resources, e.g. over-exploiting groundwater (Mariolta et al. 1997), threatens its availability in the future. Likewise, some farming practices might reduce quality of water by, for example, contaminating fresh water sources with nitrate residues from agriculture (Howden et al., 2013). As production increases, the impact of these practices worsens, hindering water availability and farmers' options for increasing production even further in the future (see B3 in **Error! Reference source not found.**).

Something similar can be said regarding soil organic matter and nutrients. As depicted in B4 (Figure B3), farming systems need organic matter and nutrients present in the soil (Bot and Benites, 2005), but high production throughputs can result in soil degradation (Tsiafouli et al., 2015; Prager et al, 2010) and eventually increase farm dependency on fertilisers and production costs.

Negative environmental effects can be reduced by using eco-friendly[1] processes and technologies if farmers decide, and have resources, to implement such practices. For instance, water consumption might be reduced by increasing rainfed agriculture, developing new surface water storage and promoting the use of wastewater (de Miguel et al., 2015; De Fraiture and Wichelns, 2010). Better water management is likely to result in higher productivity and profits that generate more resources that can be invested in even better eco-friendly processes and technologies (R7 in **Error! Reference source not found.**). Similarly, the impact on soil organic matter might be reduced by use of cover crops, crop rotations, and residue management (Turpin et al,. 2017, Smith

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[1] We use eco-friendly as umbrella term to refer to practices common in what Therond et al. (2017) describe as "biodiversity-based farming systems in globalised commodity-based food systems and territorial socio-economic contexts".

and Powlson, 2007) and result in a virtuous circle as shown in R6 (**Error! Reference source not found.**).

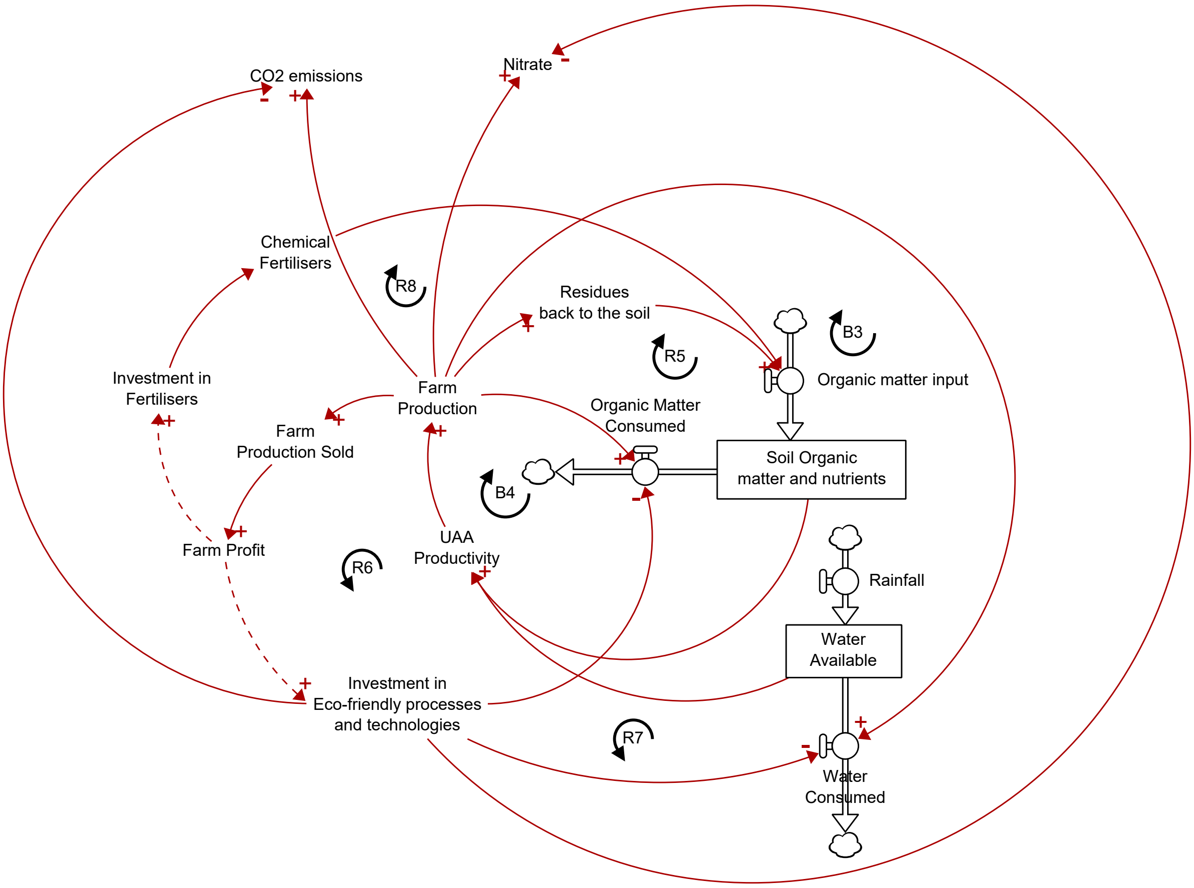

Figure B3. A stock and flow diagram showing selected dynamics between farming systems and the environment.

While there might be internal drivers for farmers to reduce their environmental impact on the water and soil, other environmental effects of agriculture like CO_2 emissions and nitrate pollution have a less obvious link to farm production and profits. For example, CO_2 emissions are a driver of climate change and, therefore, of more unpredictable and extreme weather conditions affecting farm production. However, when facing climate change farmers are more likely to focus on adaptation measures rather than mitigation measures (Hamilton-Webb et al., 2007).

8.4 Other responses: innovation/diversification/self-organization and learning

There are other decisions that farmers can make to reduce costs and increase their revenues and production. These decisions are less specific and overlap with some of the decisions explored before (e.g., investment on technology, product valorisation). However, they are worth mentioning because they can play a fundamental role in helping the system to evolve and adapt to challenges. While farmers are often risk-adverse and have conservative attitudes towards new technologies and agricultural practices (Bowman and Zilberman, 2013; Darnhofer et al., 2010; McCann, 1997), farming systems have evolved and adapted to change as response to external pressures threatening their survival (Brunori et al. 2013).

If the system starts to move towards a vicious circle where low profits limit investment in the capital needed to foster the same profits, farmers might turn their attention to improving cost efficiency. For example, limited water and nutrient availability may encourage crop rotation, adoption of new technologies and the adoption of more efficient soil management (Bowman and Zilberman, 2013). If successful, these practices increase profits, potentially reducing the adoption of further practices as the system goes back to equilibrium (see B5 in Figure)

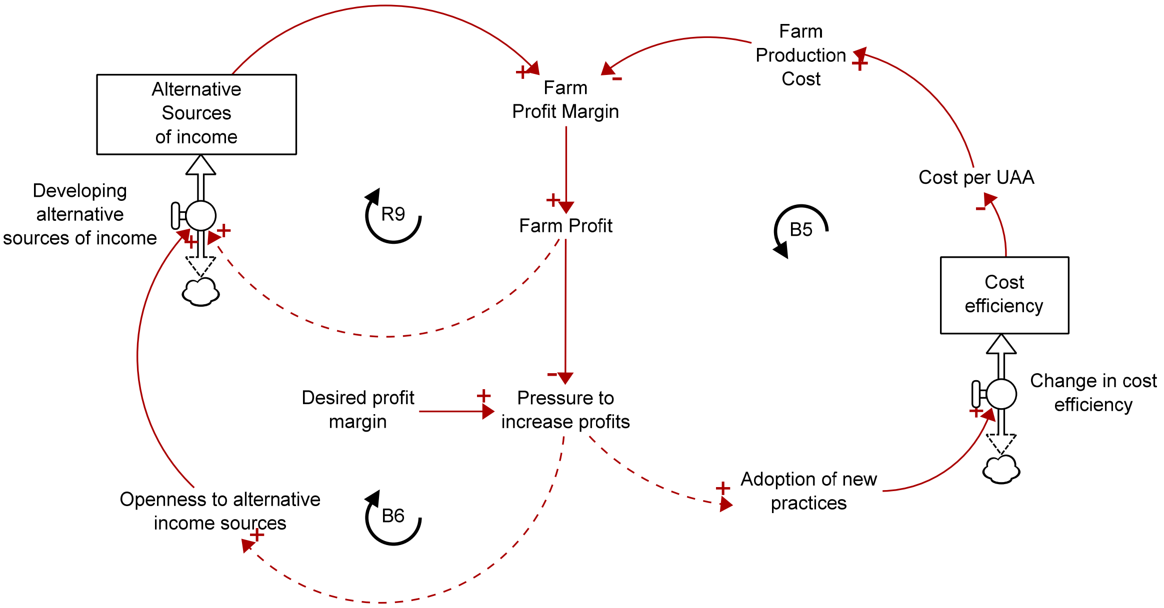

Figure B4. A stock and flow diagram showing selected mechanisms that could help farms to reduce losses in profit margins.

Another response affecting "farm profits" is functional diversification. By performing different functions and providing different products and services addressing a wider range of societal demands, farmers can reduce the impact of fluctuations in the market and yield reductions (Bowman and Zilberman, 2013, OECD, 2009; Wilson, 2008). This function of alternative sources of income as buffer mechanism is represented in the model in the feedback loop B6 (see Figure). Note that there is also a reinforcing loop between farm profits and other sources of income, as resources are needed to develop such alternatives, which may either be farm profits (see R9 in Figure) or government support.

When facing challenges, farmers might also work together and organise themselves to coordinate their response to these challenges (Giagnocavo et al., 2018; Gonzalez, 2018). Farmers might have multiple goals for organising themselves, from sharing resources (Sutherland and Burton, 2011) to negotiating better market conditions (Brusselaers and Iliopoulos, 2012) and offering opportunities for vertical integration and new markets (Strijker, 2007). In the conceptual model all these economic outcomes of "social self-organization" among farmers are aggregated as a positive effect of the former on "product value" (see B7 in Figure B5).

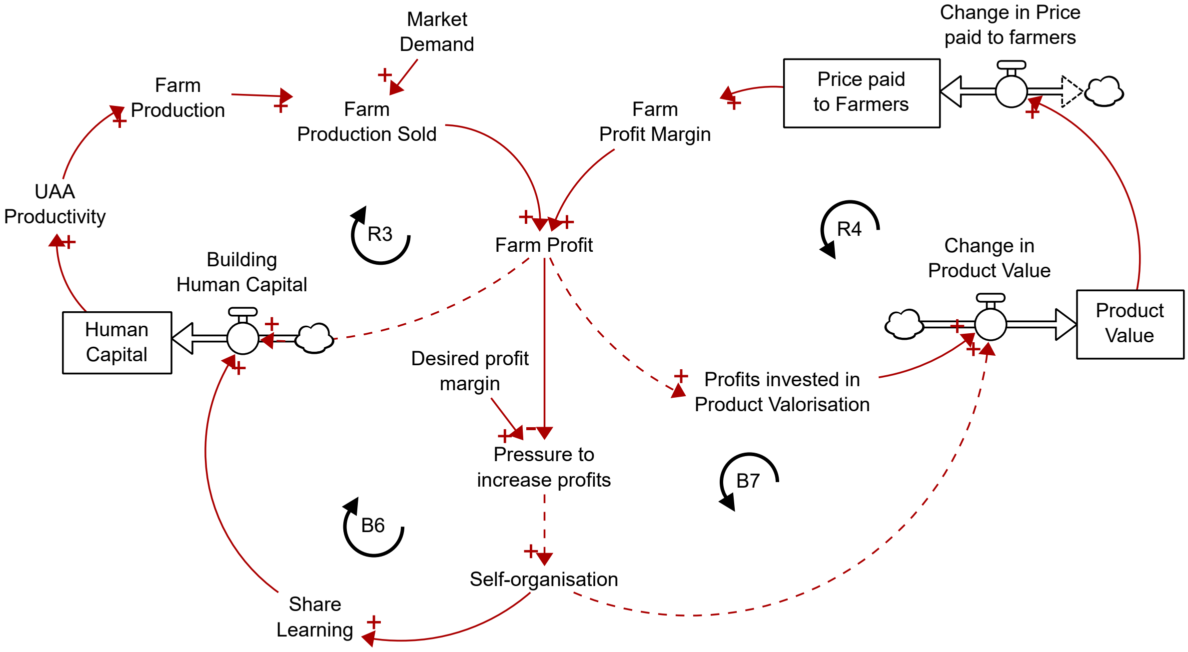

Figure B5. A stock and flow diagram showing selected mechanisms resulting from farmers self-organization.

Besides the economic benefits of social self-organization mentioned above, social self-organization also fosters opportunities for shared learning and experiences among farmers (Darnhofer et al., 2010; Westley, 2002; Scoones and Thompson, 1994). The continuous learning needed to deal with an unpredictable environment requires a continuous and informal learning process that it is fostered by combining different types of knowledge (scientific and traditional knowledge) through discussions in self-organized groups (Darnhofer et al., 2010; Scoones and Thompson, 1994). The learning generated through cooperation and self-organization increases human capital with positive effects on farm productivity and profits (see B6 in Figure B5), potentially triggering the virtuous circle of human capital (R3 in Figure B5) or complementing it when it is already in motion.

8.5 Farms and farmers

Another factor that might influence shared learning is the number of farmers in the region. A larger number of farmers is likely to result in a more diverse pool of knowledge and enhance the development of human capital in the system (R10 in Figure B6.). However, too many farmers competing for the same market might rise rivalry and decrease farmers appetite to share resources and knowledge (B8 in Figure B6.) (Cleary et al., 2019; Kuimov et al., 2018).

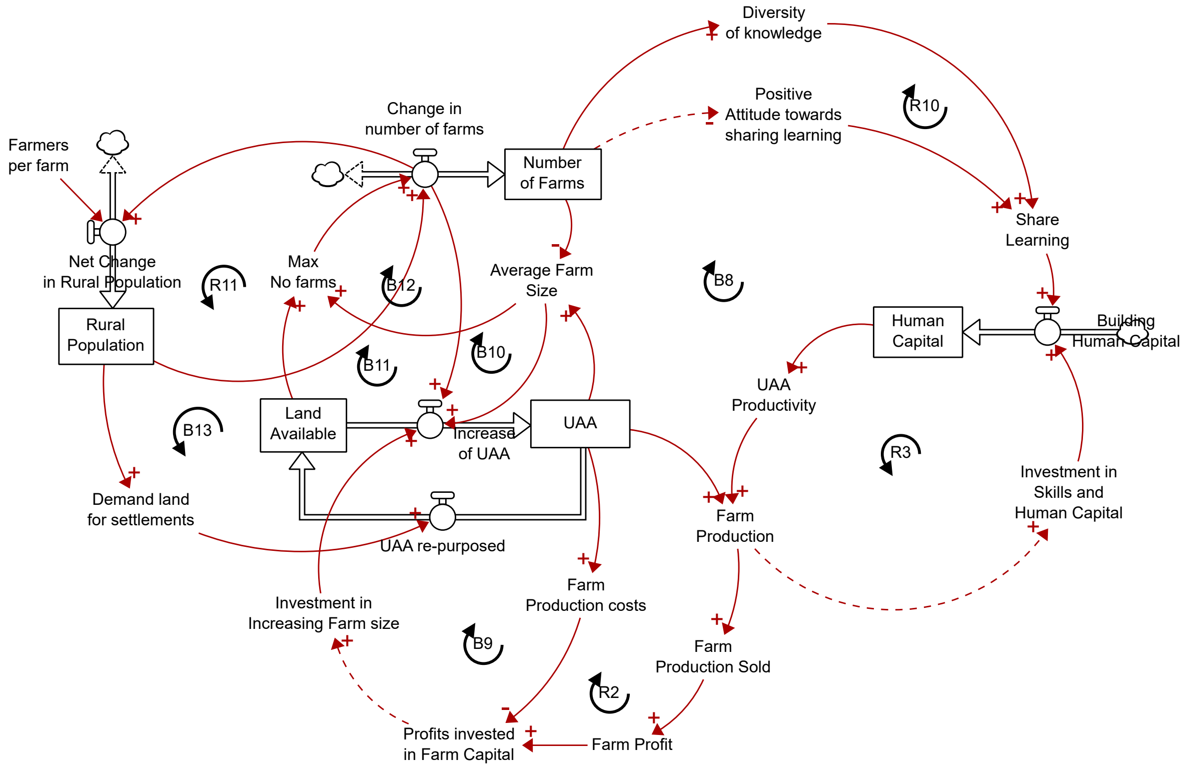

Figure B6. A stock and flow diagram showing dynamics between land availability and farming systems.

The number of farmers in the area is driven by complex interactions between two important components of the system, the land available (suitable and accessible for farming) and the size of the farms. These mechanisms (R2, B9, B10, B11 and B12 in Figure B6.) drive the system towards an equilibrium in the number of farms and their average size that enables the economies of scale needed for the system to be profitable with the amount of land available acting as limiting factor.

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As shown in Figure B6, farmers do not only compete with other farmers for land, but also with settlements that need area for housing, businesses, and services. Shifts in the demographics affecting the loops B13 and R11 (see Figure B6) might alter the system equilibrium and reduce the number of farmers, even if farming systems remain relatively profitable.

8.6 Nonlinearities and limits to success

Without further explanation, the benefits from some of the strategies discussed before might look as part of a perpetual virtuous circle but this might not be the case. As capital grows, the effect of additional investment in technology or human capital is likely to decrease, as farm productivity reaches a plateau until a new technological or other innovation breakthrough takes place. Hence, the effect of technology and human capital on UAA productivity is not linear and varies as a function of the amount of technology and human capital already present in the farming system.

This is a case of the "limits to success" mechanism described by Kim (2000, p7.) where "efforts initially lead to improved performance. Overtime, however, the system encounters a limit which causes the performance slow down or even decline" (see Figure B7). In this case, the limits are the maximum productivity per UAA that can be achieved through, for example, technology.

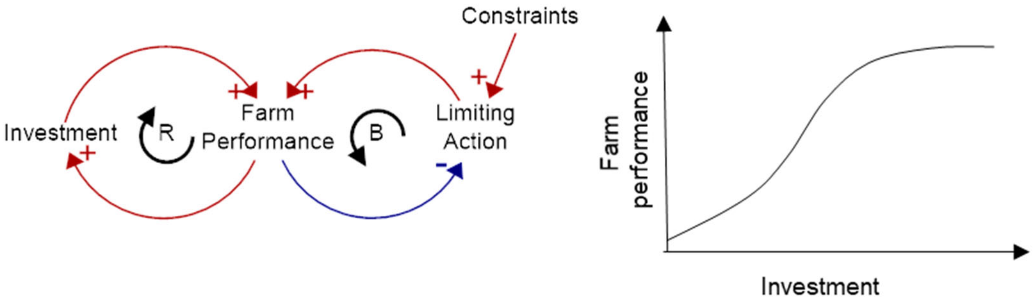

Figure B7. a) A causal loop diagram showing the system archetype 'limits to success' (adapted from Kim, 2000) and b) a chart illustrating expected behaviour of farm performance as result of the archetype 'limits to success'.

While nonlinear relationships are better described with mathematical equations and charts like the one in Figure B7, in the conceptual model we have represented them by adding the feedback loops B14 and B15 to the model (see Figure B8.). As can be seen in Figure B8., as the farm technology and human capital increase, the magnitude of their positive effect towards productivity decreases (note the minus sign in the arrow) slowing down the rate at which productivity increases as result of investing in these forms of capital.

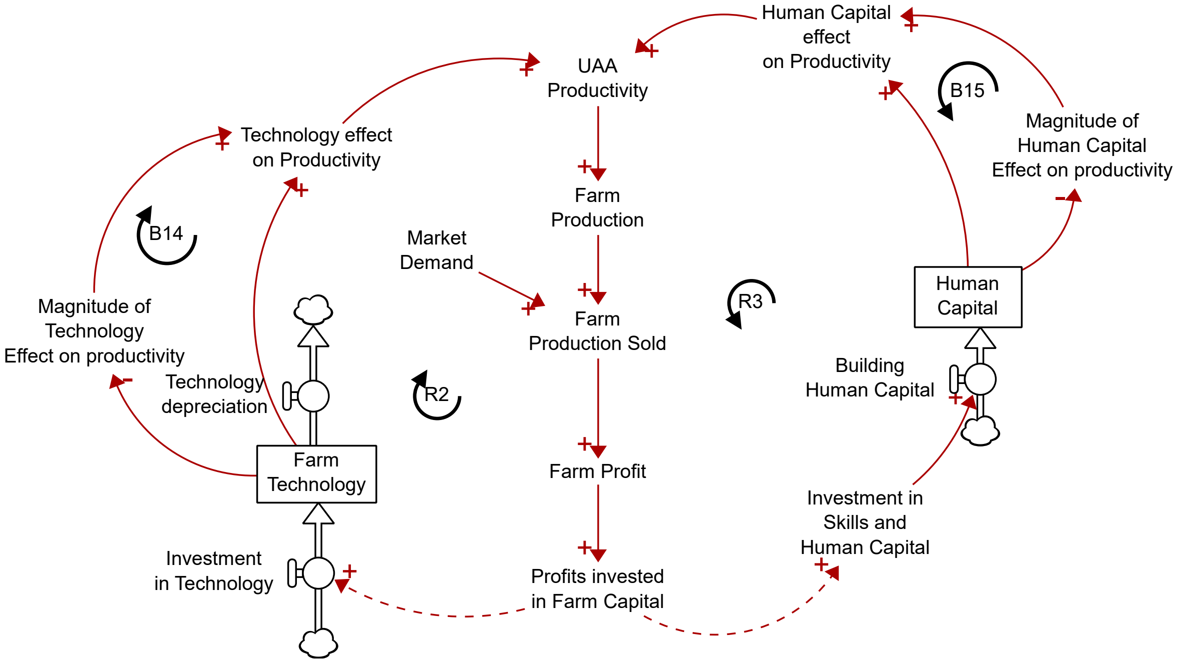

Figure B8. A stock and flow diagram illustrating limits to success of strategies based on increasing human and technological capital.

Likewise, the benefits of product valorisation are also constrained, and the change in products value is not proportional to the amount of money is invested into it. In this case, the limits to the value that can be added to the product (B16 in Figure B9) and consumers' willingness to pay additional added value is also not linear (B17 in Figure B9).

Another important nonlinearity to consider is the relation between capital and cost, because the operational costs are also a function of the capital held by the farm. For instance, more technology requires additional capital expenditure, but also maintenance costs. The effect of this relationship (B18 in Figure B9) are likely to be offset by the benefits capital brings in terms of higher productivities (R1, R2 and R3 in Figure). However, it is important to recognise the economic feasibility plays in the implementation of these strategies (Barnes et al., 2019; Darnhofer et al., 2010; Prager and Posthumus, 2010).

Economic feasibility is also an important factor to consider when implementing eco-friendly practices aiming to, for example, reduce water consumption, soil degradation and farm pollution. If production costs increase, at least in the short term, more rapidly than productivity does (R6 and R7 in **Error! Reference source not found.**), farmers might find eco-friendly practices unappealing or might not have the resources needed to sustain them (B19 in Figure B9). As

Bowman and Zilberman (2013) pointed out, even if consumers are willing to pay more for these products, the implementation costs might hinder wide implementation of eco-friendly practices (Hardesty and Leff ,2010; Pretty et al., 2005).

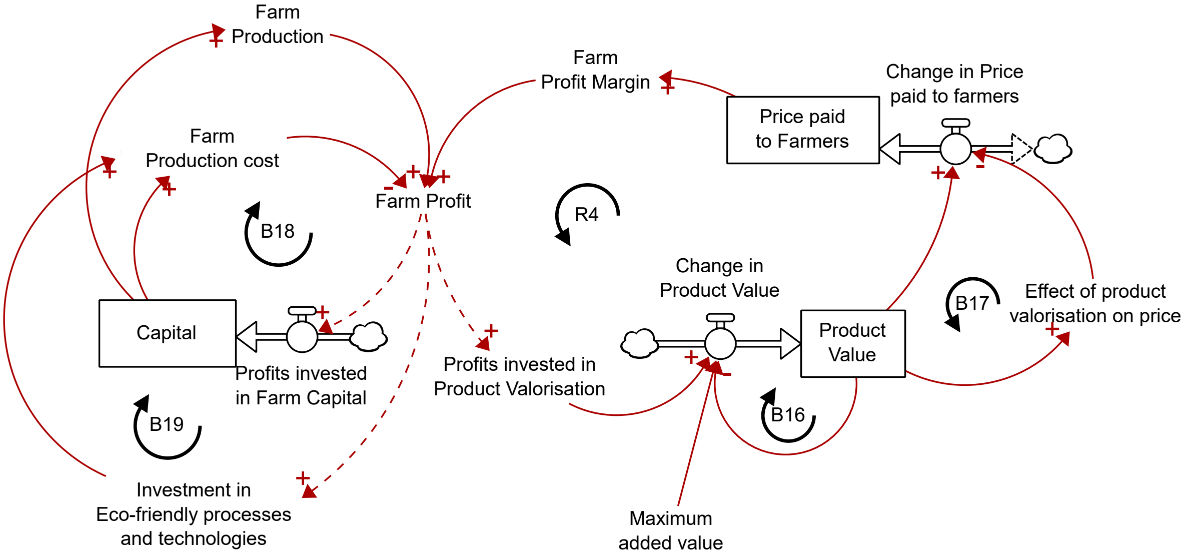

Figure B9. A stock and flow diagram illustrating limits to success mechanisms reducing the impact of several strategies on farm profits.

8.7 Linking the dots: the success to the successful

As briefly described before, farmers have different alternatives that can be used to increase their profits. An increase in farm profits can be used by farmers to increase their production throughput by either investing a) in capital (R1-UAA capital, R2-technology or R3-human capital), b) product valorisation (R4), c) alternative sources of income (R7) or d) eco-friendly processes and technologies (R9). As shown in Figure B10 all these strategies are in their own right a reinforcing mechanism that might contribute to increase farm profits and can reinforce each other.

However, since there is only a limited amount of resources that can be invested, farmers will eventually decide where to focus their efforts. While these decisions are by itself exclusive, they compete by the same resource and in a ‘success for the successful’ type mechanism (Kim, 2000), and farmers are likely to focus on the set of strategies that provide the highest return.

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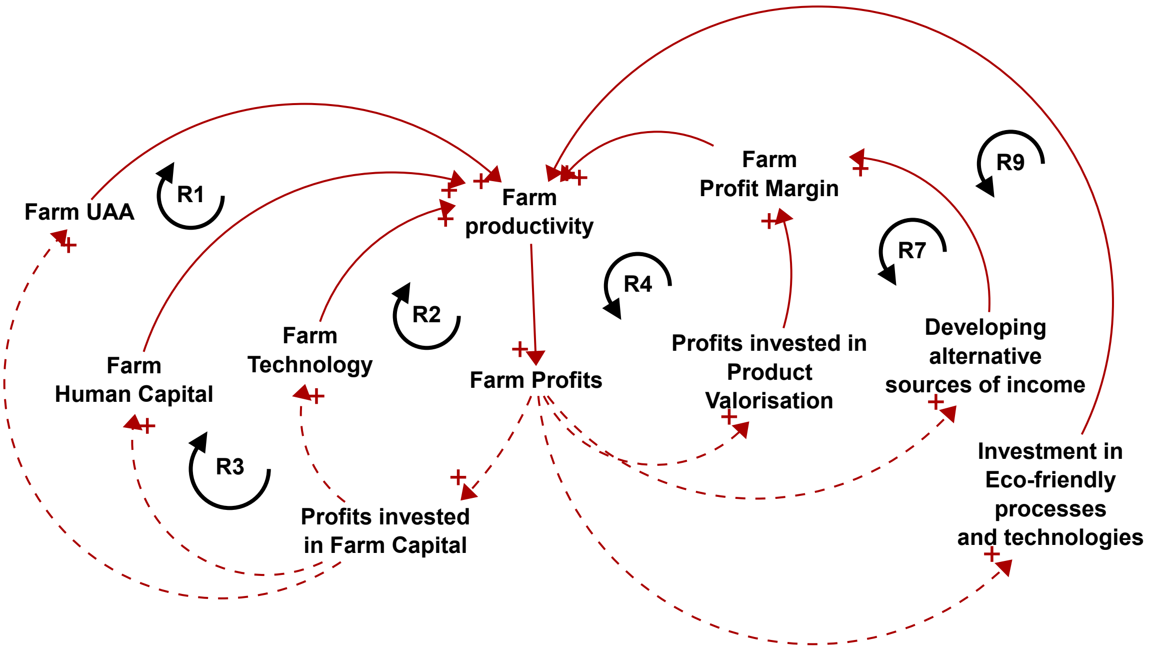

Figure B10. A causal loop diagram showing success to the successful mechanisms in the conceptual model.

Which set of strategies provides highest return will vary from case to case. In the application in section 3.8-3.10, we use the model to explore the set of alternatives that have been highlighted by stakeholders in the different SURE-Farm case studies during the FoPIA-SURE-Farm 2 workshops (Accatino et al. 2020).

Without being able to quantify the strength of the different feedback loops and the impact they might have on farm performance, it is difficult to hypothesise which strategies might prevail in a particular case. However, the conceptual model allows to conceptualise the synergies and interactions between different strategies and their impact on the system ability to respond to challenges, as well as offering hints on the conditions that could enable their successful implementation.

This Project has received funds from the European Union’s Horizon 2020 research and innovation programme under Grant Agreement No. 727520

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5 Appendix C. Overview of strategies.

Table A1. Current strategies and future strategies for maintaining the status quo, and alternative future systems in 11 EU farming systems. Current strategies are largely based on FoPIA-SURE-Farm 1. Full tables were earlier presented in FoPIA-SURE-Farm 2 case study reports in Accatino et al. (2020). Bold font indicates that these strategies were mentioned during the workshop for a specific system. Normal font indicates that, based on the discussions during the workshop, it seems likely that strategies will be applied in certain systems. In some case studies, this distinction was not made.

BG-Arable		**Current system**	**Future systems**						
Strategy	**Domain**		**Status quo**	**Innovation and technology improvement**	**Processing and increasing value added**	**Crop diversification**	**Exit farming / change of sector**	**Collaboration**	**Moving the farm to a different region**
Changes into production technologies and modernization	Agronomic	V	V	**V**	V	**V**		V	V
Diversification of crops	Agronomic	V		V		**V**			
Preservation of soil quality	Environmental			**V**	V	V			
Application of good farming practices	Environmental	V	V	V	V	V	V	V	V
Increase of the farmed land	Economic	**V**	**V**						
Preservation of the marketing of the products	Economic	V			**V**			**V**	
Introduction of insurances	Economic	V		V					
Marketing/production/processing cooperatives	Social				**V**			**V**	
Stimulating succession and improved attractiveness of the sector	Social	V	V	V	V		V		V
Better information exchange and field visits	Social			**V**	V	V		V	V
Policy support	Institutional	V		V	V			V	
Better cooperation with research institutions and universities	Institutional			**V**	V				

NL-Arable (1)		**Current system**	**Future systems**				
Strategy	**Domain**		**Status quo**	**Alternative crops**	**Precision agriculture**	**Nature inclusive**	**Collaboration & water**
Extend knowledge on soil & varieties	Agronomic	V	V	V	V	V	V
Better varieties (starch content, nematode resistance)	Agronomic	V	V	V	V	V	V
Precision agriculture	Agronomic	V	V		**V**	**V**	V
Exchange land with dairy farms	Agronomic	V	V		**V**	**V**	V
Changing crop rotation	Agronomic		**V**	**V**		**V**	
Protein crops for animal and human consumption	Agronomic			**V**			
Different way of fertilizing (alternative) crops	Agronomic			**V**			
Increasing water use efficiency	Agronomic			**V**			V
Applying drones (for early risk detection and damage assessment)	Agronomic				**V**		
Improve circularity	Agronomic		V	**V**	V	V	
Scaling up	Economic	V	V		V		
Increase value of starch products	Economic	V	V	V	V	V	V
Reduce costs (in general)	Economic	V	V				
Reduce crop inputs	Economic	V			**V**	**V**	
Have land available outside contract farming	Economic	V	V				
Developing new business models	Economic			V	V	**V**	
Introduction of new value chains	Economic			**V**			
Having a good marketing strategy	Economic			**V**			
High value products	Economic			V	**V**		
Improve soil quality	Environmental	V	V	**V**	V	**V**	V
Maintain water locally in canals	Environmental						**V**
Take lower laying lands out of production	Environmental						**V**
Actively replenishing ground water levels	Environmental						**V**

NL-Arable (2)		**Current system**	**Future systems**				
Strategy	**Domain**		**Status quo**	**Alternative crops**	**Precision agriculture**	**Nature inclusive**	**Collaboration & water**
Land consolidation / redesign of the landscape	Environmental					**V**	**V**
Nature friendly interventions at field level (buffer strips, strip cropping, green manures etc.)	Environmental					**V**	
Customized water levels	Institutional						**V**
Relax constraining regulations (water management, collaboration, taxes)	Institutional						**V**
Rewarding services with regard to nature	Institutional			V		**V**	**V**
Adapting trading policies	Institutional					**V**	
Allowing genetic improvement techniques (Crispr-Cas)	Institutional				**V**		
Raising awareness about soil quality	Social	V	V	V	V	V	V
Raising awareness about water availability	Social	V	**V**				**V**
More contact between consumers and producers	Social			V			
Precision agriculture as shared responsibility of processors and farmers	Social				**V**		
Collective action	Social			V			**V**

UK-Arable		**Current system**	**Future systems**		
Strategy	**Domain**		**Status quo**	**Desirable system**	**Likely system**
Land tenure arrangements	Agronomic		V	V	
Reintroduction of livestock	Agronomic			V	V
Responsible management	Agronomic			V	
Agricultural diversification	Economic		V		V
Increased area farmed	Economic	V	V		
Non-agricultural diversification	Economic	V			V
Adoption of agri-environmental schemes	Environmental	V	V	V	V
Adoption of conservation farming	Environmental			V	
Collaboration	Institutional		V	V	V
Knowledge Exchange	Institutional	V	V	V	V
Farmer led exchange	Social	V		V	
Peer Learning	Social	V	V	V	V

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DE-Arable&Mixed		**Current system**	**Future systems**			
Strategy	**Domain**		**Status quo**	**Organic farming**	**Better societal appreciation**	**Intensification**
Extend knowledge on local varieties and climate smart techniques	Agronomic			V		V
Better varieties (drought resistant)	Agronomic			V		V
Precision agriculture	Agronomic	V	V			V
Integrate knowledge from R&D	Agronomic	V	V	V	V	V
Cost leadership through cost reduction	Economic					V
Increase value of raw materials	Economic			V		V
Increase share of profit in value chain	Economic			V		
New varieties with climate services (tree crops)	Environmental			V	V	
Improve efficiency of irrigation schemes	Environmental	V	V	V		V
Improve rural infrastructure	Institutional	V	V	V	V	V
Create alternative jobs and social/cultural offers	Institutional			V	V	V
Stronger regulation of international agricultural trade system	Institutional			V		
Simplify system of labelling and certification	Institutional			V	V	V
De-bureaucratization (duration of approval, frequency of controls, paper work for new investments)	Institutional			V		V
Fair prices instead of direct payments	Institutional			V	V	V
Align funding with locally specific conditions	Institutional			V	V	V
Improve marketing of farms and the whole sector	Institutional			V	V	V
Improve culture of trust	Social			V	V	V
Better cooperation between all stakeholders	Social			V	V	V

RO-Mixed		Current system	Future systems				
Strategy	**Domain**		**Status quo**	**Commercial specialization of mixed family farms**	**Cooperation / multifunctionality**	**Organic farming**	**Alternative crops / livestock**
Information actions	Agronomic	V	V	**V**	**V**	**V**	**V**
Ensuring the correctness of paperwork	Institutional	V	V	V	V	V	V
Quality rather than quantity	Institutional			**V**		V	V
Creation of producers' associations / groups	Economic	V	V	**V**	**V**	**V**	**V**
Informing campaigns regarding the eco-conditionality rules	Institutional	V	V			V	
Regulations / sanctions / penalties coming from authorities	Institutional	V	V	V	V	V	V
Land consolidation and technologization	Economic	V		**V**		**V**	
New technologies, new machinery and equipment adapted to the needs of small farms	Agronomic	V			**V**		
New crops / varieties to improve diversity.	Agronomic	V			V	V	**V**
Diversification of activities; farm products processing	Economic	V		**V**	**V**		**V**
Expansion of organic farming	Economic					**V**	
Succession could be stimulated by offering old retiring farmers decent pensions or life annuities, and to young farmers easier access to finance and adapted financial instruments for funding operating capital and investment capital	Social	V	V	**V**	V		
For unskilled labour: continuous adult training and programs for exiting agriculture	Social	V	V	**V**			
For skilled labour: better adaptation of school / university training to the demand in the agricultural sector	Social	V	V	**V**		**V**	**V**
More stable policies and fiscal regulations	Institutional	V	V	**V**	**V**	**V**	**V**
Improved consultancy system	Institutional	V	V	**V**	**V**	**V**	**V**
Facilities and incentives for cooperation	Institutional	V	V	**V**	**V**	**V**	**V**
Funding / credit instruments adapted to small farms to enable their development and enlargement to medium-sized farms	Institutional	V		**V**	V	V	
Technological and managerial improvement to cope with climate changes	Environmental	V	V	**V**	V	**V**	V
Insurance instruments adapted to small farms	Economic	V	V	**V**	**V**		
Diversification of activities	Economic	V		**V**	**V**		V

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ES-Sheep (1)		**Current system**		**Future systems**	
Strategy	**Domain**		**Status quo**	**Semi-intensive system**	**Hi-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	**V**	
Research for sanitary conditions of the ovine sector (new vaccines, medicaments, etc.)	Agronomic			**V**	**V**
Implementation of sanitary conditions (hygiene, spaced animals, etc.)	Agronomic	V	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	**V**	
Financial products to cover droughts	Economic	V	V		**V**
Opening up a foreign market	Economic	V	V	**V**	**V**
Short channel boost	Economic	V	V		**V**
Openness of local slaughterhouses	Economic				**V**
Diversification (on-farm)	Economic	V	V	**V**	
Alternative income sources (off-farm)	Economic	V	V		**V**
Investment in the farm assets	Economic	V	V	V	V
Costs reduction and flexibility	Economic	V	V	V	V
Sales contracts	Economic	V	V	V	V
Access to market information	Economic	V	V	V	V
Improvement of the access to pastures and stubble fields	Environmental	V	V		**V**
Use of technology for control of grazed pastures	Environmental				**V**
Research in methane emissions from ovine sector	Environmental			**V**	**V**
Use of technology for real-time communication with administration	Institutional			**V**	**V**

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ES-Sheep (2)		**Current system**		**Future systems**	
Strategy	**Domain**		**Status quo**	**Semi-intensive system**	**Hi-tech extensive system**
Trained administration staff in region specificities	Institutional			**V**	**V**
Reduce 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					**V**
Remuneration to the sector for contribution to public goods	Institutional				**V**
Improve legislation in relation to wild fauna	Institutional	V	V		**V**
Innovation of laws for products origin and certification	Institutional			V	**V**
Promote generational renewal (early retirements, access to land, etc.)	Institut./Social			**V**	**V**
Creation of shepherd schools	Institut./Social				**V**
Promotion of lamb meat consumption	Institut./Social	V	V	**V**	**V**
Promotion of local breeds outside the region	Institut./Social				**V**
Improvement awareness of sector contribution to public goods	Institut./Social	V	V	V	**V**
Associations and cooperatives	Social	V	V	V	V
Improvement of quality of live (work intensity reduction with technology)	Social	V	V	**V**	**V**

BE-Dairy **Strategy**	**Domain**	**Current system**	**Future systems** **Status quo***
Financial support (buying milk powder stocks, subsidies)	Institutional	V	V
Scale enlargement (total milk production/farm; investments of cooperatives to process additional milk)	Agronomic	V	
Innovation (manure recycling, new technology)	Agronomic	V	V
Diversification (green energy, maintain diversity of dairy farms, broaden business)	Agronomic	V	
Intensification (Increase efficiency (e.g. feedings, genetic improvement)	Agronomic	V	
Financial risk management (financial buffer, futures, cyclic investing)	Economic	V	V
Organization in cooperatives, producer organizations	Social	V	
Cooperation with cooperation with value chain actors such as processors, retailers, and technology providers	Social	V	V
Improve entrepreneurial skills (use of market information, be prepared for exit or succession, improve data management, have a long term strategy)	Agronomic	V	V
Conversion to organic production	Agronomic	V	
Stimulate learning settings with multi actor participation, other minded people	Social	V	V
Improve long term vision of policies, improve coherence between different policy areas that pursue different policy objectives	Institutional		V

* A desk study was performed, as COVID-19 did not allow to organize a workshop. No alternative systems were identified with stakeholders.

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FR-Beef		**Current system**	**Future systems***			
Strategy	**Domain**		**Status quo**	**All-export**	**Only French market**	**Tourism**
Developing farmers’ associations and cooperatives	Social	V	V		V	V
Diversification of the production	Agronomic	V	V			V
Diversification of buyers	Economic	V	V	V	V	V
Facilitating young farmers’ installation	Social		V		V	V
Professionalise the workforce	Social		V	V	V	V
Investing in new technologies and practices	Agronomic	V	V	V	V	V
Improving food self-sufficiency in the region	Agronomic	V	V		V	V
Improving feed self-sufficiency in the region	Agronomic	V	V	V	V	
Developing grass fattening	Agronomic	V	V	V	V	
Adopting practices that mitigate floods	Agronomic	V	V			
Adopting practices that fulfil social expectations	Social	V	V		V	V
Bank help in debt limitations	Economic	V	V		V	V
Good risk assessment by banks	Economic	V	V		V	V
Advancement of payment by cooperatives	Economic	V	V		V	V
Insurance schemes	Economic	V	V	V	V	V
Improve life quality at work	Social	V	V		V	V
Facilitating exchange of information between farmers	Social	V	V		V	V
Monitoring farmers’ situations	Social	V	V		V	V
Insurance replacement service	Social	V	V	V		
Policy supports direct payments and insurance schemes	Institutional		V	V	V	V
Building a positive image of the Bourbonnais	Social				V	V
Improve the coordination among actors of the value chain	Social/Economic				V	V
Improve access of farmers to public markets	Institutional				V	
Promoting communication between farmers and other actors	Social				V	V
Better tax policy	Institutional				V	

* A desk study was performed, as COVID-19 did not allow to organize a workshop. Future systems and strategies were identified by researchers and experts.

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SE-Poultry		**Current system**	**Future systems**			
Strategy	**Domain**		**Status quo**	**Large farms**	**Self-sufficiency fodder**	**Robots**
Knowledge management	Agronomic	**V**	**V**	**V**	**V**	**V**
	Economic	**V**	**V**	**V**	**V**	**V**
	Institutional	**V**	**V**	**V**		
Technology adaptation	Agronomic	**V**	**V**	**V**	**V**	**V**
	Economic	**V**	**V**	**V**	**V**	**V**
Farm size	Agronomic			V	V	V
	Economic	V		V	V	V
	Institutional	V		V	V	V

IT-Hazelnut		**Current system**	**Future systems**				
Strategy	**Domain**		**Status quo**	**Sustained demand (high and stable prices)**	**Product valorization**	**Technological innovation**	**Eco-friendly agriculture**
Mechanization	Agronomic	V	V	V		V	V
Agro-environmental policies	Environmental	V					V
Open international markets	Economic			V			
Control of environmental requirements	Institutional						V
Consortia for technical advise	Institutional	V	V			V	V
Promotional policies	Institutional			V	V		
CAP support	Institutional	V				V	V
Training activity	Social					V	
Value chain activities – cooperation among stakeholders	Social	V	V	V	V	V	V

PL-Horticulture				**Future systems**		
Strategy	**Domain**	**Current system**	**Status quo**	**Horticulture production**	**Shelter farming**	**Local organic production**
Simplification of regulations	Institutional			**v**		
Education campaigns for consumers	Economic/Social			**v**		
Additional actions in the RDP targeting quality and profitability of agricultural production	Institutional				**v**	
Preferential taxation system for shelter farming	Institutional/Economic				**v**	
Creation and promotion of a locally recognized brand	Institutional/Economic				**v**	
Increase in the number of ecological farms	Social					**v**
Intensification of vertical cooperation	Social/Economic	v		**v**		**v**
Diversifying outlets (entering new markets)	Economic					**v**
State support	Institutional	v				
Horizontal cooperation	Social/Economic	v		v	v	v
Marketing	Economic	v		v	v	v
Insurance	Economic	v				
Enduring	Economic	v				
Diversification	Economic	v				

6 Appendix D. Association matrix of resilience attributes

Table D1. Association matrix of resilience attributes (see Appendix A). If the value in a cell is 1.00 it means that 100% of the strategies that enhance the resilience attribute indicated in the row also enhance the resilience attribute indicated in the column. The first 13 attributes were assessed in FoPIA-SURE-Farm 1, the additional 9 have also been considered as relevant. This matrix shows synergies and possible overlap. The table can be digitally enlarged.

	Reasonably profitable	Coupled with local and natural capital (production)	Functional diversity	Response diversity	Exposed to disturbance	Spatial and temporal heterogeneity (farm types)	Optimally redundant (farms)	Supports rural life	Socially self-organized	Appropriately connected with actors outside the farming system	Infrastructure for innovation	Coupled with local and natural capital (legislation)	Diverse policies	Ecologically self-regulated	Optimally redundant (crops)	Optimally redundant (nutrients & water)	Spatial and temporal heterogeneity (land use)	Optimally redundant (labour)	Globally autonomous and locally interdependent	Reflective and shared learning	Honours legacy	Builds human capital
Reasonably profitable	1.00	0.13	0.30	0.16	0.17	0.08	0.05	0.08	0.19	0.27	0.17	0.09	0.05	0.06	0.02	0.02	0.02	0.05	0.11	0.09	0.03	0.14
Coupled with local and natural capital (production)	0.15	1.00	0.29	0.12	0.04	0.12	0.10	0.08	0.17	0.15	0.25	0.21	0.06	0.35	0.12	0.19	0.08	0.10	0.12	0.21	0.13	0.19
Functional diversity	0.44	0.35	1.00	0.40	0.14	0.23	0.09	0.12	0.14	0.33	0.14	0.05	0.05	0.16	0.16	0.07	0.05	0.09	0.14	0.09	0.02	0.09
Response diversity	0.29	0.17	0.49	1.00	0.31	0.14	0.09	0.09	0.17	0.06	0.14	0.11	0.09	0.11	0.17	0.06	0.03	0.03	0.23	0.14	0.00	0.06
Exposed to disturbance	0.44	0.08	0.24	0.44	1.00	0.08	0.04	0.08	0.04	0.20	0.28	0.12	0.12	0.08	0.04	0.00	0.00	0.04	0.24	0.08	0.00	0.08
Spatial and temporal heterogeneity (farm types)	0.24	0.29	0.48	0.24	0.10	1.00	0.33	0.24	0.10	0.10	0.10	0.10	0.05	0.33	0.14	0.00	0.14	0.19	0.05	0.00	0.05	0.10
Optimally redundant (farms)	0.16	0.26	0.21	0.16	0.05	0.37	1.00	0.47	0.32	0.16	0.05	0.21	0.16	0.05	0.16	0.05	0.05	0.53	0.16	0.21	0.21	0.32
Supports rural life	0.20	0.16	0.20	0.12	0.08	0.20	0.36	1.00	0.20	0.16	0.12	0.16	0.12	0.08	0.04	0.04	0.04	0.36	0.08	0.12	0.16	0.36
Socially self-organized	0.23	0.17	0.11	0.11	0.02	0.04	0.11	0.09	1.00	0.26	0.17	0.08	0.00	0.04	0.00	0.02	0.02	0.13	0.13	0.55	0.17	0.66
Appropriately connected with actors outside the farming system	0.47	0.22	0.39	0.06	0.14	0.06	0.08	0.11	0.39	1.00	0.17	0.14	0.08	0.03	0.00	0.00	0.00	0.11	0.14	0.39	0.11	0.33
Infrastructure for innovation	0.27	0.32	0.15	0.12	0.17	0.05	0.02	0.07	0.22	0.15	1.00	0.12	0.02	0.12	0.07	0.05	0.00	0.12	0.00	0.24	0.05	0.34
Coupled with local and natural capital (legislation)	0.16	0.29	0.05	0.11	0.08	0.05	0.11	0.11	0.11	0.13	0.13	1.00	0.34	0.05	0.05	0.05	0.03	0.13	0.13	0.16	0.08	0.11
Diverse policies	0.18	0.18	0.12	0.18	0.18	0.06	0.18	0.18	0.00	0.18	0.06	0.76	1.00	0.00	0.00	0.00	0.00	0.18	0.12	0.18	0.06	0.12
Ecologically self-regulated	0.18	0.82	0.32	0.18	0.09	0.32	0.05	0.09	0.09	0.05	0.23	0.09	0.00	1.00	0.18	0.18	0.18	0.00	0.09	0.05	0.00	0.00
Optimally redundant (crops)	0.09	0.55	0.64	0.55	0.09	0.27	0.27	0.09	0.00	0.00	0.27	0.18	0.00	0.36	1.00	0.18	0.09	0.09	0.09	0.00	0.00	0.00
Optimally redundant (nutrients & water)	0.09	0.91	0.27	0.18	0.00	0.00	0.09	0.09	0.09	0.00	0.18	0.18	0.00	0.36	0.18	1.00	0.00	0.09	0.09	0.18	0.09	0.09
Spatial and temporal heterogeneity (land use)	0.14	0.57	0.29	0.14	0.00	0.43	0.14	0.14	0.14	0.00	0.00	0.14	0.00	0.57	0.14	0.00	1.00	0.00	0.00	0.00	0.00	0.00
Optimally redundant (labour)	0.19	0.31	0.25	0.06	0.06	0.25	0.63	0.56	0.44	0.25	0.31	0.31	0.19	0.00	0.06	0.06	0.00	1.00	0.13	0.13	0.13	0.50
Globally autonomous and locally interdependent	0.32	0.27	0.27	0.36	0.27	0.05	0.14	0.09	0.32	0.23	0.00	0.23	0.09	0.09	0.05	0.05	0.00	0.09	1.00	0.09	0.00	0.23
Reflective and shared learning	0.14	0.26	0.10	0.12	0.05	0.00	0.10	0.07	0.69	0.33	0.24	0.14	0.07	0.02	0.00	0.05	0.00	0.05	0.05	1.00	0.29	0.67
Honours legacy	0.13	0.44	0.06	0.00	0.00	0.06	0.25	0.25	0.56	0.25	0.13	0.19	0.06	0.00	0.00	0.06	0.00	0.13	0.00	0.75	1.00	0.81
Builds human capital	0.18	0.20	0.08	0.04	0.04	0.04	0.12	0.18	0.69	0.24	0.27	0.08	0.04	0.00	0.00	0.02	0.00	0.16	0.10	0.55	0.25	1.00

7 Appendix E. Impact of Covid19 on farming systems in Europe through the lens of resilience thinking

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Abstract

Resilience is the ability to deal with shocks and stresses, including the unknown and previously unimaginable, such as the Covid19 crisis. The aim of this paper is to assess responses of farming systems (FS) to this crisis and to assess them from the perspective of resilience thinking. We build on a resilience framework developed in the SURE-Farm project and on ongoing resilience assessments in 11 FS across Europe through which we have an in-depth understanding of the 'pre-Covid19 situation' in each FS. This includes insights whether an FS has an enabling (or constraining) environment, who are the relevant system actors beyond farms, and what are the social, economic and ecological functions to be delivered by the system. The analysis allows us to understand which resilience resources and strategies were mobilised in different FS and thereby to explain differences in the ability of FS to cope with and respond to the crisis. Furthermore, the approach enables us to put crisis responses in a broader resilience perspective and to assess whether responses might enhance (or constrain) future resilience. Thus, our analysis allows to draw policy and industry relevant conclusions how to increase resilience of farming systems.