Alternative systems and strategies to improve future sustainability and resilience of farming systems across Europe: from adaptation to transformation

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Declaration of interest

None

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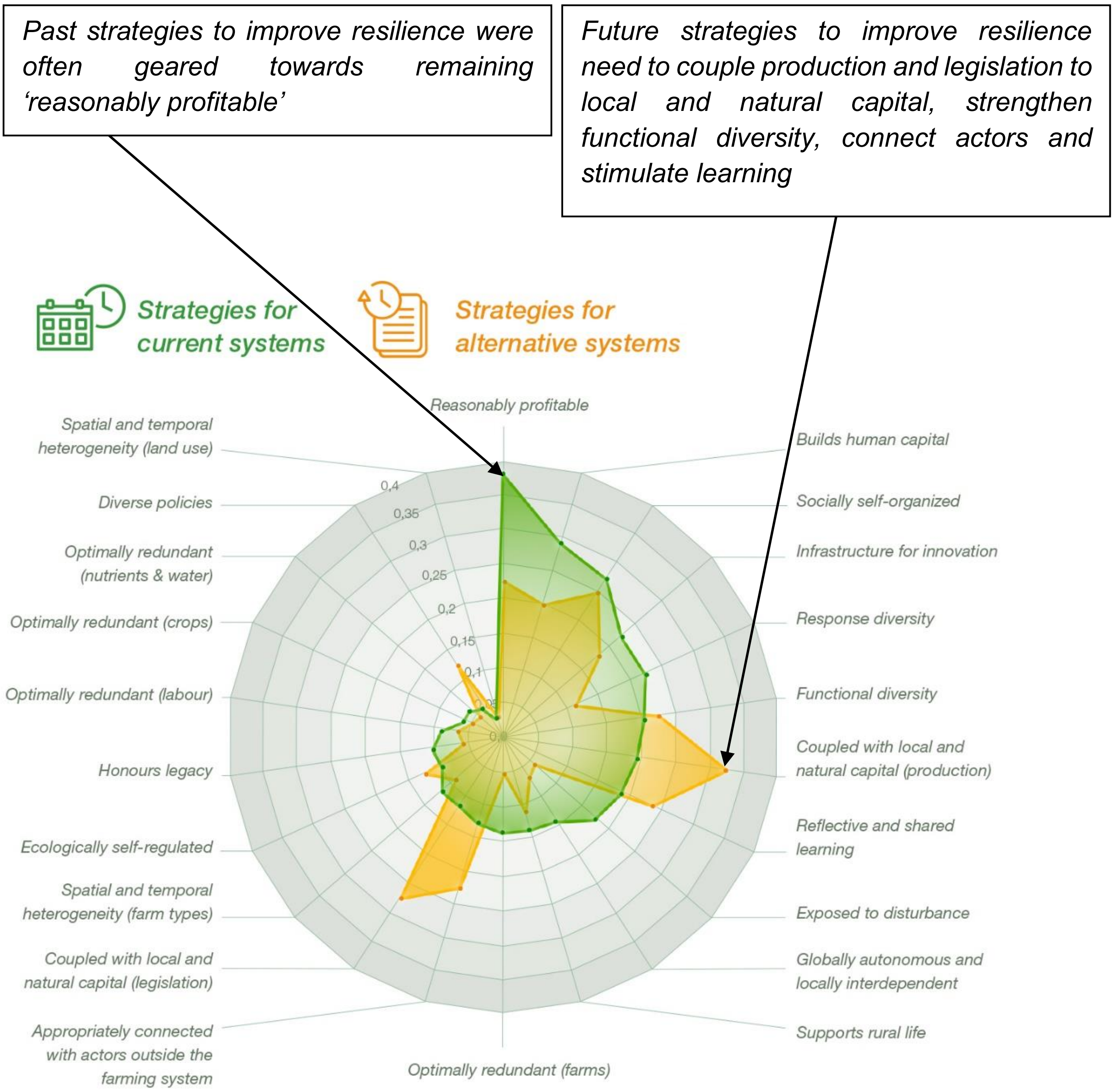
Highlights

- Backcasting was used to identify alternative European farming systems supported by stakeholders
- Low economic viability limited farming system actors to improve sustainability and resilience
- To strengthen resilience, production and legislation need to be coupled to local and natural capital
- Desired alternative systems are diverse but only compatible with the 'sustainable paths' scenario
- To get stakeholders along, incremental adaptation rather than radical transformation should be sought

Graphical abstract



Abstract

According to stakeholders, many European farming 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). To accelerate a transition process towards sustainable and resilient agriculture, this study aimed to identify actor-supported alternative systems across 10 European farming systems, and to identify associated future strategies that contribute to strengthening resilience attributes, using a backcasting approach. This paper synthesizes 1) the participatory identification of desired alternative systems and their expected performance on sustainability and resilience, 2) the participatory identification of strategies to realize those alternative systems, 3) the contribution of identified past and future strategies to 22 resilience attributes, and 4) the compatibility of the status quo and alternative systems with different future scenarios, the Eur-Agri-SSPs. Many identified alternative systems emphasized technology, diversification and organic and/or nature friendly farming, while in some farming systems also intensification, specialization, better product valorization, collaboration, and creating an attractive countryside could increase sustainability and resilience. Low economic viability limited farming system actors to pay attention to environmental and social functions. Further, most alternative systems were adaptations rather than transformations. Many stakeholders had difficulty to envisage systems without the main products (e.g., starch potato in NL-Arable, sheep in ES-Sheep and hazelnut in IT-Hazelnut), but in few cases transformative systems were designed (e.g. local organic farming in PL-Horticulture and RO-Mixed). Sustainability and resilience can be enhanced when alternative systems and strategies are combined, thereby improving multiple functions and attributes at once. In particular, production and legislation need to be coupled to local and natural capital. Identified alternative systems seem only compatible with Eur-Agri-SSP1 ‘agriculture on sustainable paths’. This requires policies at EU-level that stimulate macro-level social, institutional, economic, and

technological developments that strengthen this scenario. We conclude that to get stakeholders along, incremental adaptation rather than radical transformation should be sought. The identification of alternative systems is only a start for the transition process. Their analysis, along with the strategies identified, need to trigger the involvement of farmers and other 'enabling actors' inside and outside the farming systems to make a change, and where needed, systems can evolve into more transformative systems.

Keywords: resilience, sustainable development, backcasting, stakeholders, participatory, scenarios

1 Introduction

Farming systems in Europe are increasingly challenged by economic, environmental, social, and institutional changes (Meuwissen et al., 2020). 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 recent years, resulting in yield reductions. In addition, 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 and Reidsma, 2021; 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 the resulting lock-downs caused specific shocks, notably for systems relying on catering, export and agritourism (Meuwissen et al., 2021; Savary et al., 2020). All these shocks and stresses affect the sustainability and resilience of European 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. General action points for initiating transformation are listed, but more knowledge is needed to identify which specific (and local) actions lead to more sustainable and resilient agricultural systems. In addition, knowledge is needed on which actions correspond with the wishes, capacities and willingness of farming system actors, as they are key in initiating actions on the ground.

In the SURE-Farm project, we developed a framework to assess the resilience of farming systems (Meuwissen et al., 2019), which can be used for the purpose of identifying sustainability and resilience enhancing strategies. 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 resilience 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.

Three resilience capacities can be 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). Accordingly, adaptation is a change in the composition of inputs, production, marketing and risk management but without changing the structures and feedback mechanisms of the farming system, while transformation is a change in the internal structure and feedback mechanism of the farming system into a desired direction in response to either severe shocks or enduring stress that make business as usual impossible. Deliberate transformation requires resilience thinking, first in assessing the relative merits of the current versus alternative systems in potentially more favourable stability domains (i.e., a domain where a system is robust within certain thresholds of control variables), and second in fostering resilience of the new development trajectory (i.e., towards an alternative, transformed system) and the new basin of attraction (i.e., a system with a more sustainable stability domain) (Folke et al., 2010).

Based on the framework by Meuwissen et al. (2019) a range of quantitative and qualitative methods was employed to investigate sustainability and resilience in 11 European farming systems (Meuwissen et al., 2022; Meuwissen et al., 2021). 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 analyse current systems based on statistical data (Dardonville et al., 2021; Reidsma et al., 2010; Slijper et al., 2020), and to simulate the impact of specific scenarios on specific indicators (e.g., Herrera et al., 2022), 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 a rural area for residents and visitors is difficult to capture with quantitative indicators). In addition, to assess resilience, dynamics of multiple processes need to be investigated simultaneously (Kinzig et al., 2006; Walker and Salt, 2012). 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., 2010). Qualitative approaches are needed to understand the dynamics of farms and to address the above-mentioned issues (Darnhofer, 2014). 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). In addition, in order to follow-up on an assessment and allow for a transition process, farming system actors (stakeholders and the enabling environment; see Meuwissen et al., 2019) need to be part of the assessment (Quist and Vergragt, 2006). Hence, we first assessed sustainability and resilience of *current* European farming systems with a structured participatory method (Paas et al., 2020; Reidsma et al., 2020a), and next, we addressed sustainability and resilience of *future* farming systems in collaboration with relevant actors (Paas et al., 2021a; Paas et al., 2021b).

According to stakeholders in the first round of workshops in the selected European farming systems, sustainability and resilience of current systems is low (Paas et al., 2020; Reidsma et al., 2020a). In the first part of the second round of workshops, on future systems, it was concluded that many of the current 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) (Paas et al., 2021a). A quantitative modelling study confirmed closeness to critical thresholds for the Dutch case study, and showed that only actively implementing strategies allowed the system to remain resilient (Herrera et al., 2022). However, across Europe strategies have, so far, mainly focussed on robustness, and lack attention for adaptability and transformability (Buitenhuis et al., 2020b; Paas et al., 2020; Reidsma et al., 2020a).

Alternative systems and associated strategies are thus needed. These were addressed in the second part of the workshops on future systems, and are the focus of this paper. The aim of this paper is to identify actor-supported alternative systems across 10 European farming systems that contribute to sustainability and resilience, and to identify associated future strategies that contribute to strengthening resilience attributes. In addition, the compatibility of the *status quo* and alternative systems with the developments in different future scenarios is assessed, as resilience depends both on internal and external factors.

2 Material and methods

2.1 Participatory assessment of resilience and sustainability of farming systems

Case study farming systems covered different sectors, farm types, products and challenges in European agriculture (Table 1; Appendix A; Bijttebier et al., 2018; Meuwissen et al., 2022). All farming systems cover a region within a country, but the scale differs per case study.

Table 1. The 10 case study farming systems, including date and number of participants in the FoPIA-SURE-Farm II workshops.

Acronym	Specialization, location	Date	Total	Farmer	Govern-ment	Industry	NGO	Agricultural advice	Research	Finance	Other
BG-Arable	Large-scale arable farming, Bulgaria	16/01/2020	19	8	5	1	2	3			
NL-Arable	Intensive arable farming, the Veenkoloniën region in the Netherlands	10/12/2019	22	8	3	2	2		3	2	2
UK-Arable	Arable farming, East of England in the United Kingdom	15/01/2020	5		1		2	2			
DE-Arable&Mixed	Large-scale corporate arable farming with additional livestock activities, East Germany	06/02/2020	15	5	4	1	1	1	1		
RO-Mixed	Small-scale mixed farming, North-East Romania	12/03/2020	16	6	2	3			5		
FR-Beef	Extensive beef cattle systems, the Massif Central, France	Desk study	-								
ES-Sheep	Extensive sheep farming, Northeast Spain	14/02/2020	18	7	4	1		3	3		
SE-Poultry	High-value egg and broiler systems, Southern Sweden	31/01/2020 & 03/02/2020	9	5		3					1
IT-Hazelnut	Small-scale hazelnut production, Central Italy	21/01/2020	14	5	2	1	2	3	1		
PL-Horticulture	Fruit and vegetable farming, the Mazovian region in Poland	29/11/2019	12	7	1		1	3			

Based on the resilience framework, a Framework of Participatory Impact Assessment for Sustainable and Resilient EU farming systems (FoPIA-SURE-Farm) was developed. FoPIA-SURE-Farm includes two series of participatory workshops, both including a preparation and evaluation phase by researchers, focussing on current (FoPIA-SURE-Farm I) and future (FoPIA-SURE-Farm II) sustainability and resilience. This paper synthesizes workshop results from the second half of FoPIA-SURE-Farm II for 10 European farming systems. These results build on previous steps from the FoPIA-SURE-Farm I approach. These previous steps are briefly described in the two following paragraphs. After that, the methodological steps are described that lead to the results presented in this paper.

FoPIA-SURE-Farm I (Nera et al., 2020; Paas et al., 2020; Reidsma et al., 2020a), was conducted in the 10 case studies presented in Table 1 and a case study on dairy farming in Flanders, Belgium. In each case study, one workshop of around six hours was held between November 2018 and March 2019. 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 (Paas et al., 2020). In brief, the workshops focused 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 past 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 resilience attributes and their potential contribution to the robustness, adaptability and transformability of the farming system.

In FoPIA-SURE-Farm II (Paas et al., 2021b), a workshop of around four hours was held between November 2019 and March 2020 in 9 case studies, and in 1 case study (FR-Beef) a desk study was performed, as the COVID-19 crisis prevented the realization of the workshop. In the desk study, inputs from stakeholders and experts, based on earlier work and literature, were considered. Only specific results from this case study are included. A desk study was also performed in the aforementioned Belgian case study, but this case is excluded from the current paper as it focused on the status quo only. The number of participants ranged between 5 and 22, with a total of 128 participants (Table 1; Paas et al., 2021a). The first half of the workshop was focused on forecasting in relation to maintaining the status quo and system decline in case critical thresholds would be exceeded, and results for the 10 European farming systems and the one in Belgium are described in Paas et al. (2021a). This forecasting approach included an assessment of: 1) the development of current systems; 2) identification of critical thresholds whose exceedance can lead to large and permanent system change; 3) an assessment of the developments when critical thresholds are exceeded. These steps build on FoPIA-SURE-Farm I, as the previously identified most important functions, challenges and resilience attributes were considered for this assessment.

The second half of the workshop was focused on alternative systems and strategies to achieve these, using a backcasting approach (Figure 1; this paper). The essence of backcasting consists of creating desirable sustainable future visions, followed by looking back at how these desirable futures can be achieved, by planning follow-up activities and developing strategies leading to that desirable future (Quist and Vergragt, 2006). The backcasting approach included the remaining steps of FoPIA-SURE-Farm II: 4) participatory identification of desired alternative systems towards 2030 and their expected improved performance of sustainability and resilience; 5a) participatory identification of strategies to achieve those alternative systems. The evaluation phase included 6) an assessment by researchers on the compatibility of alternative systems with the developments of exogenous factors as projected in different future scenarios (for more detail, see section 2.2).

Methods and results of all six steps of FoPIA-SURE-Farm II are described in detail for extensive sheep farming in Huesca, Spain, in Paas et al. (2021b). Paas et al. (2021b) present results from the first part across European farming systems, providing forecasts for current systems. In this paper, we will synthesize results from the second part across European farming systems, backcasting alternative systems (for details, see Accatino et al., 2020). In the evaluation phase, we added 5b) an assessment by researchers of the contribution of the identified past and future strategies to 22 resilience attributes, to assess and synthesize their impact on resilience across case studies. All methodological steps are further explained in the next section. General guidelines were followed, but slight deviations were made in specific case studies depending on the needs of the stakeholders.

2.2 Backcasting to design and evaluate alternative systems and strategies

Starting with step 4 of FoPIA-SURE-Farm II, we present the identification of alternative systems for the future (Figure 1). All participants in the workshops were asked individually to envisage one or more alternative systems they desired towards 2030 if challenges, functions and/or resilience attributes would cross critical thresholds. 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 common alternative systems. Suggestions by individuals were grouped into 2-4 alternative systems. These were considered to be potential future systems, along with maintaining status quo, and system decline (when essential requirements are not met), which serve as a reference.

For the cross-case study comparison, alternative systems were categorized according to the most important direction that an alternative system is taking (e.g., specialization), 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. The categories that came forward in this study are also not exhaustive in the sense that they do not cover all directions that alternative systems can take.

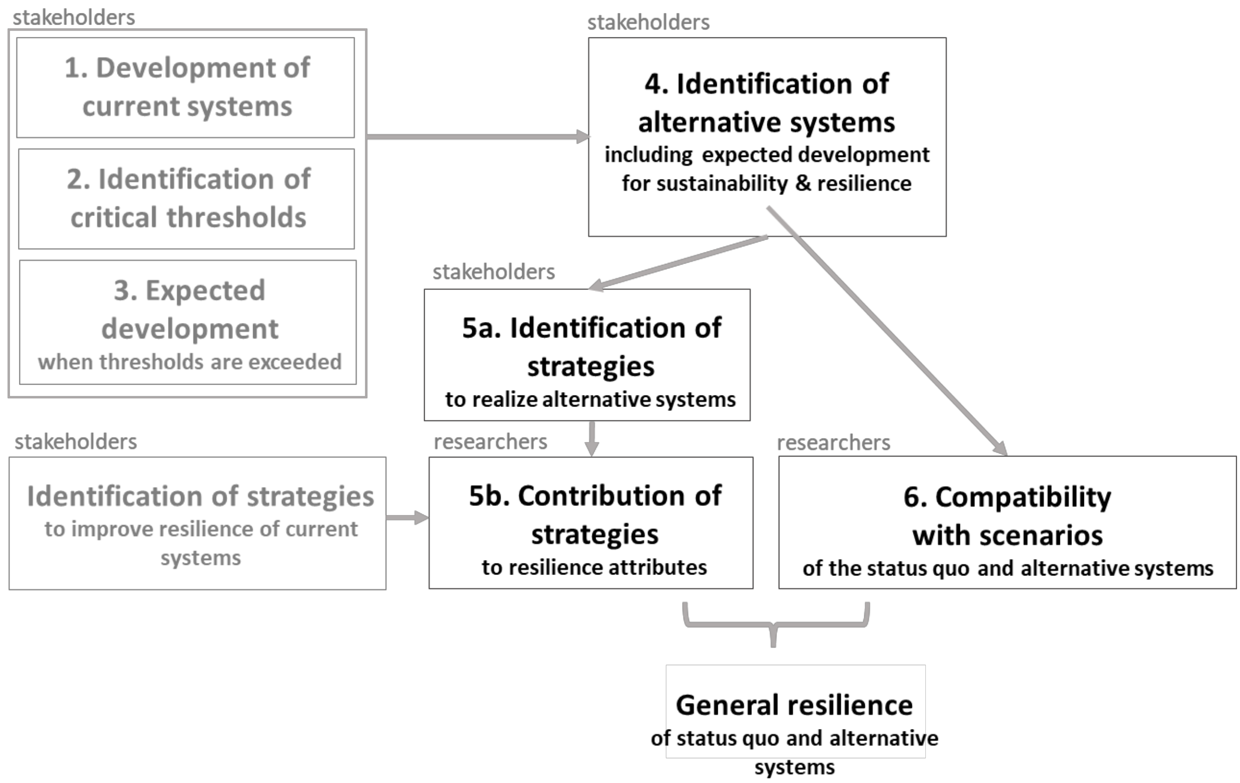


Figure 1. Steps in the backcasting approach of FoPIA-SURE-Farm II to identify alternative systems that contribute to sustainability and resilience, and to identify associated strategies and developments in future scenarios that contribute to general resilience. Step 4-6 (in black) refer to backcasting and are addressed in this paper. Step 1-3 (in grey) refer to the forecasting part of FoPIA-SURE-Farm II, which serves as input for the assessment, together with 'Identification of strategies to improve resilience of current systems' coming from FoPIA-SURE-Farm I. Step 1-5a are stakeholder-based, and step 5b and 6 are researcher-based.

Subsequently, stakeholders were divided in small groups and within each group one alternative system was discussed (or in subsequent sessions when the number of participants was too small) with regard to main function indicators, resilience attributes and enabling conditions. A selected set (based on FoPIA-SURE-Farm I) of main function indicators and resilience attributes was discussed per case study (see Table SM1.5 of Paas et al., 2021b) as critical system changes are expected to be determined by a small set of key variables (Kinzig et al., 2006). Developments were classified as strongly negative (-2), moderately negative (-1), no impact (0), moderately positive (+1) and strongly positive developments (+2). For the synthesis across case studies, the minimum and maximum of expected developments per function (eight in total) and resilience attribute (13 in total) were evaluated and translated into arrows with the same meaning. These were compared with the average expected developments for the status quo and system decline (Paas et al., 2021a).

Step 5a was the identification of strategies that would be needed to reach the alternative systems and to improve resilience. This was done in the same groups discussing alternative systems. These future strategies were classified as agronomic, economic, social or institutional, and listed along with strategies that were applied in the past to improve resilience, as identified in FoPIA-SURE-Farm I (Paas et al., 2019). In some case studies, the strategies identified in FoPIA-SURE-Farm I were complemented with strategies identified using other SURE-Farm approaches (e.g. Reidsma et al., 2019; Soriano et al., 2020).

A farming system can be resilient to specific challenges (specified resilience), and strategies can be implemented to deal with such challenges, but this does not necessarily imply that the farming system is capable to deal with the unknown, uncertainty and surprise (general resilience). General resilience can be judged based on the presence of resilience attributes (Meuwissen et al., 2019; Cabell and Oelofse, 2012). An additional step 5b was therefore included to assess the impact of strategies on general resilience. After the workshops, researchers assessed the contribution (either yes or no) of the identified past and future strategies to 22 resilience attributes (see Appendix B for full description). In the assessments with stakeholders, 13 out of these 22 were selected to be discussed, but researchers were assumed to be able to address all 22, allowing to assess which ones from the full list were most important (also in comparison to the selected 13). 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 B). The 22 attributes are associated to the 5 general resilience principles (system reserves, tightness of feedbacks, diversity, modularity and openness; Appendix B; Meuwissen et al., 2019). The first and last author of this paper did a first assessment across all case studies, this was checked per case study by case study partners, and evaluated again by the first and last author. Results were synthesized based on the relative share of strategies contributing to a resilience attribute, where the contribution of future strategies to reach alternative systems was compared with (past) strategies implemented for current systems.

General resilience also relates to the compatibility of farming systems with external factors. Some resilience attributes relate to the farming system itself, and some to the enabling environment, and the latter is influenced by scenario narratives. Mitter et al. (2019, 2020) developed five scenarios for European agriculture and food systems, called Eur-Agri-SSPs. These scenarios are plausible and internally consistent views of the future and are in line with the Shared Socio-Economic Pathways (SSPs) as developed for the climate change research community. They include Eur-Agri-SSP1 – Agriculture on sustainable paths, Eur-Agri-SSP2 – Agriculture on established paths, Eur-Agri-SSP3 – Agriculture on separated paths, Eur-Agri-SSP4 – Agriculture on unequal paths, and Eur-Agri-SSP5 – Agriculture on high-tech paths. Table 3 of Mitter et al. (2020) presents storyline elements and directions of change for the five Eur-Agri-SSPs (see also: https://eur-agri-ssps.boku.ac.at/eur-agri-ssps-2/).

In step 6 of FoPIA-SURE-Farm II, the compatibility of the future farming systems (status quo and alternative systems) with the directions of change of the storyline elements as projected in these five Eur-Agri-SSPs was assessed. For each future farming system, case study partners indicated how important an increase in the scenario elements (related to the sections 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 scenario elements were based on Mitter et al. (2020), with -1, 0 and 1 indicating negative, no and positive changes, respectively. Multiplication of the importance of developments for future systems with expected developments of scenario elements was used as an approximation for compatibility. Final compatibility scores per future system per scenario 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 to 0 weak incompatibility, 0 to 0.33 weak compatibility, 0.33 to 0.66 moderate compatibility, and 0.66 to 1 strong compatibility. An example for ES-Sheep is presented in Paas et al (2021c). For the comparison across case studies, compatibility scores per Eur-Agri-SSP were averaged per category of the alternative systems.

3 Results

3.1 Alternative farming systems

Many desired alternative systems are adaptations rather than transformations of current systems (Table 2; see Appendix A for details). For example, in NL-Arable, starch potato production is at the core of the farming system, and stakeholders had difficulties identifying alternatives without starch potatoes. Similarly, in ES-Sheep, alternatives identified what is needed to keep sheep farming. Integration and diversification were emphasized in many alternatives, but changes in the main products were not envisaged. Some systems can be considered transformative considering the change in intensity of production. For example, the 'desirable system' in UK-Arable is supposed to be regenerative. The local organic farming system in PL-Horticulture is a real transformation, as it changes the whole food system.

The alternative systems could broadly be grouped in eight categories 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, FR-Beef and PL-Horticulture, alternative systems focused on intensification or specialization were seen as relevant and viable options. Also in SE-Poultry, further intensification was considered as an option. Many case studies considered alternatives which focused on technology development, where generally new technologies should also allow for improving the maintenance of natural resources and biodiversity (e.g. precision agriculture in NL-Arable, high-tech extensive production in ES-Sheep, robots in SE-Poultry). 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, such as food production and maintaining natural resources. 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). In many case studies they were seen as ambitious and subject to many enabling conditions.

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 (BG-Arable, DE-Arable&Mixed, NL-Arable, SE-Poultry, IT-Hazelnut, ES-Sheep), and/or over time at the farming system level (e.g., the likely system may evolve into the desired system in UK-Arable).

Table 2. Alternative systems per category per case study. Categories are based on the most important direction that an alternative system is taking

	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)**
Intensifica-tion				Intensification		Semi-intensive		Large farms			3
Specializa-tion					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
Collabora-tion	Collaboration	Collaboration & water			Cooperation / multifunctio-nality						3
Attractive countryside				Better societal appreciation			Development of tourism			Sustained demand (high and stable prices)	3
Diversifica-tion	Crop diversifi-cation	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 FR-Beef, a desk study with researchers was conducted instead of a workshop with stakeholders.

[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.

3.2 Development of future systems

Future systems include maintenance of the *status quo*, system decline when critical thresholds are exceeded and the desired alternative systems. We use the function and attribute development under continued status quo and system decline, which are described in Paas et al. (2021b), as points of reference. A summary is provided in the remainder of this paragraph. When maintaining status quo under the current challenges, 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, for the continued status quo, no large negative changes 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.

We note that in farming systems with current low economic performance (i.e. PL-Horticulture, ES-Sheep, BG-Arable, SE-Poultry), there was a larger tendency to identify alternative systems that mainly focus on improving economic functions, while there was increased attention for improving social functions when economic performance was perceived to be higher (i.e. RO-Mixed, NL-Arable, IT-Hazelnut) (see Appendix C for details). Focussing on improving economic performance, often seems to be at the expense of social and environmental functions.

Minimum and maximum developments of farming system functions in alternative systems indicate that for most functions at best moderate improvements are expected (Table 3; Appendix C). 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” (evaluated once) and “biodiversity & habitat” (evaluated four times), the average maximum development is expected to be strongly positive, while the average minimum development is expected to be negative and stable, respectively. This indicates that for these functions, alternative systems seem to take different directions, and stakeholders foresee trade-offs.

Under alternative systems, “food production” is perceived to at least not 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 continue in the “likely” alternative system. In multiple case studies, some alternative systems resulted in negative developments for “food production” (BG-Arable), “bio-based resources” (DE-Arable&Mixed, RO-Mixed), “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.

Table 3. 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 (↓) **and brown** imply strong negative, down-right (↘) **and orange** moderate negative, straight (→) stable, right-up (↗) and light green moderate positive, and up (↑) **and dark green** strong positive developments, with others in-between.

			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] Results for FR-Beef are not included in this table.

Minimum and maximum 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 evaluated 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 multiple alternative systems.

3.3 Identification of past and future strategies

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

Agronomic strategies included diversification, implementation of more technology, and improved knowledge and research on crops and livestock (NL-Arable, ES-Sheep, SE-Poultry, DE-Arable&Mixed, RO-Mixed). In many cases, these were strategies already employed by part of the farms, which can only be up-scaled in combination with economic, institutional and social strategies.

While in the past, strategies to remain resilient focused on the economic domain, when envisaging future strategies attention shifted to other domains. Strategies that had been important in the past, such as increasing farm size and intensity, do not contribute to most alternative systems. However, in many case studies, economic strategies such as diversification of income sources (ES-Sheep, FR-Beef, RO-Mixed, UK-Arable) remained important in at least one of the alternative systems. Economic strategies thus remained relevant, but the nature changed. For example, in NL-Arable, for three out of four alternative systems economic strategies were identified, 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 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) and financial support in general (PL-Horticulture, IT-Hazelnut, RO-Mixed).

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. Important strategies in the social domain included cooperation and/or knowledge sharing among farming system actors (in a value chain and/or cooperative) (all case studies having socially oriented strategies), and 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).

Alternative systems cannot be reached by implementing one strategy, but various agronomic, economic, institutional and social strategies need to be combined, and implemented by different actors (see Appendix D for required strategies per alternative system).

3.4 How do past and future strategies impact resilience attributes?

Past strategies to cope with specific challenges and improve resilience were often geared towards maintaining profitability, such as intensification and scale enlargement, and to a lesser extent towards other resilience attributes, like building human capital, social self-organization, facilitating infrastructure for innovation, enhancing response and functional diversity, and coupling production with local and natural capital (Figure 2; see Appendix B for explanation of resilience attributes). For these resilience attributes, negative developments were expected when maintaining status quo (Table 3), while they were considered important for resilience capacities (Paas et al, 2019; Reidsma et al. 2020). There has been limited attention for improving redundancy and spatial and temporal heterogeneity.

In order to reach more sustainable and resilient future systems, stakeholders argue that maintaining profitability remains important, but specifically more attention is needed for strategies coupling production and legislation with local and natural capital (Figure 2). Strategies to improve these resilience attributes include improving soil quality, improving circularity, reducing inputs, using varieties adapted to local climatic conditions, local branding, and policies that support these production practices. Further potential for strengthening ecological processes lies in increasing functional diversity (e.g. diversification of varieties, crops, livestock, markets, on-farm and off-farm activities) and creating ecologically self-regulated systems (e.g. alternative fertilization, reintroducing livestock; often also considered under coupled with local and natural capital). Likewise, strengthening social processes requires social self-organization (e.g. improve culture of trust, creation of shepherd schools, creation and promotion of a locally recognized brand), an adequate level of connections of farming system actors with actors outside their system, and diverse policies that simultaneously address robustness, adaptability and transformability.

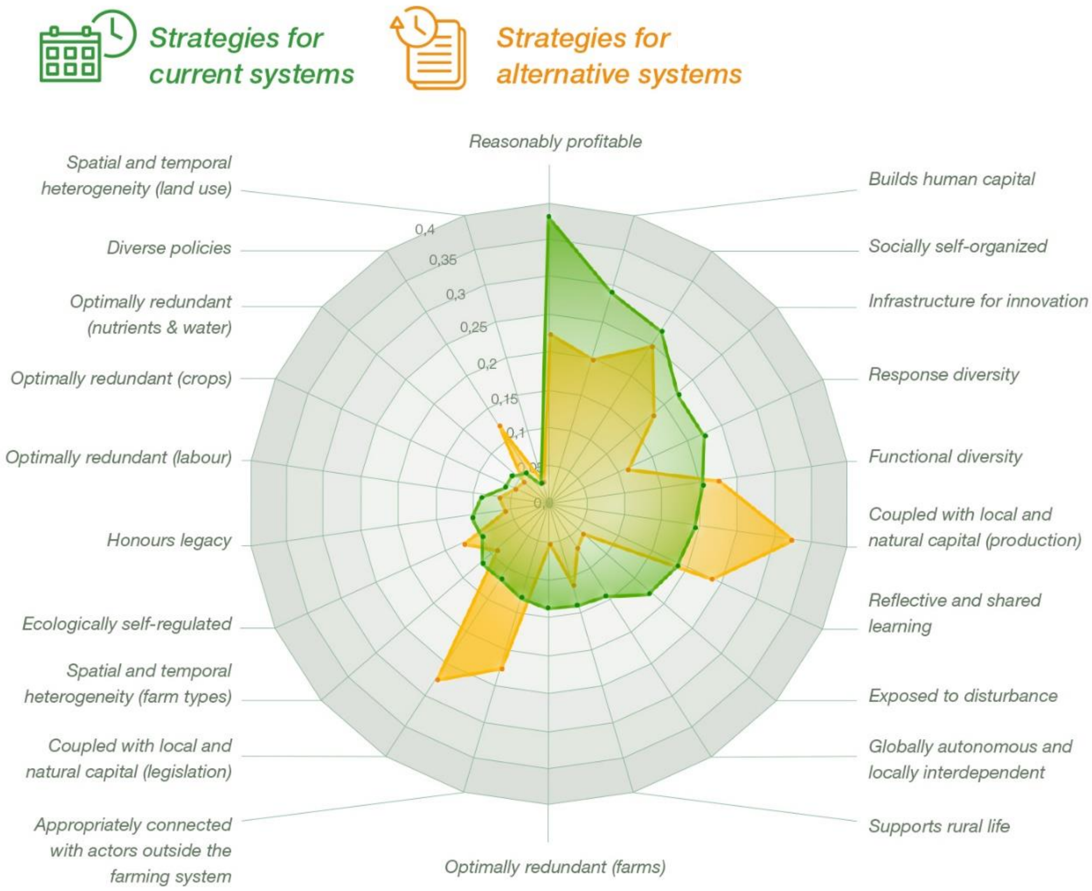


Figure 2. The contribution to resilience attributes of the identified strategies implemented and proposed in farming systems. The green line shows the ratio of (past) strategies implemented for current systems contributing to an attribute, and the orange line the ratio of future strategies for alternative systems contributing to an attribute. Attributes are ordered, starting with the attribute to which most past strategies contributed.

3.5 Compatibility of farming systems with future scenarios

Although different strategies are needed for different alternative systems, alternative systems generally thrive in the same scenario. Most future systems, including maintaining the status quo, are most compatible with Eur-Agri-SSP1 "Sustainable paths" (Table 4; Appendix E). This is mainly due to favourable developments regarding policies and institutions and technology, which are environment-focused (e.g., agri-environmental payments increase), corresponding with enabling conditions and strategies for most future systems (Appendix E). 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. For arable systems, the need for improving soil quality also explains lesser compatibility with other Eur-Agri-SSPs, where maintenance of natural resources is expected to stay stable or even decline. 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. The most compatible development would be towards alternative systems primarily driven by organic / nature friendly production under Eur-Agri-SSP1, but also product valorization and intensification seem to be very compatible with this scenario.

Table 4. Average compatibility of alternative system categories with Eur-Agri-SSPs. With values -1 to -0.66: strong incompatibility, -0.66 to -0.33: moderate incompatibility, -0.33 to 0: weak incompatibility, 0 to 0.33 weak compatibility, 0.33 to 0.66: moderate compatibility, and 0.66 to 1: strong compatibility. Colours reflect compatibility categories. Aggregated results from nine case studies.

		Average compatibility score with Eur-Agri-SSPs				
Category future systems	Future systems [#]	SSP1 "Sustain-able"	SSP2 "Established"	SSP3 "Separated"	SSP4 "Unequal"	SSP5 "High-tech"
Status quo	9	0.56	0.31	-0.60	0.15	0.29
Intensification	3	0.63	0.45	-0.32	0.20	0.27
Specialization	2	0.50	0.35	-0.67	0.24	0.37
Technology	6	0.61	0.30	-0.52	0.21	0.25
Product valorization	2	0.68	0.26	-0.79	0.00	0.23
Collaboration	3	0.63	0.26	-0.75	0.16	0.24
Attractive countryside	2	0.50	0.43	-0.62	0.26	0.52
Diversification	5	0.69	0.24	-0.50	0.07	0.14
Organic / nature friendly	6	0.71	0.36	-0.74	0.10	0.21
Average[1]		**0.62**	**0.32**	**-0.60**	**0.15**	**0.26**

[1]Results for FR-Beef are not included in this table.

With regard to environmental developments needed for at least maintaining the status quo, it becomes clear that Eur-Agri-SSP2 "Established paths" will not bring the developments that are needed to avoid exceeding environmental thresholds in the arable systems (e.g., resource depletion will continue). Still, supported by generally positive developments in the economy, policies and institutions (e.g., international trade agreements improve) and technology (e.g., technology uptake in agriculture improves), most case studies are weakly compatible with Eur-Agri-SSP2. However, for case studies where further intensification was seen as a possibility for the future (ES-Sheep, SE-Poultry; but also RO-Mixed), Eur-Agri-SSP2 seems to be moderately compatible, while also the systems emphasizing an attractive countryside (specifically in IT-Hazelnut) are moderately compatible.

In Eur-Agri-SSP3 “Separated paths”, 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. Eur-Agri-SSP3 seems, therefore, most incompatible with most future systems in all case studies, especially because many farming systems currently produce for international markets and/or depend on technology and maintenance of remaining natural resources. SE-Poultry is an exception to this, because of the current experienced mismatch between 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 (under the condition that technology and feed are also locally produced). 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.

Eur-Agri-SSP4 “Inequality paths” shows a mix of positive and negative developments. Storyline elements in relation to population, such as rural-urban linkages are expected to decrease while technology levels are expected to go up. Elements related to economy and policies and institutions are showing both positive and negative developments. In Eur-Agri-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 Eur-Agri-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 Eur-Agri-SSP5 “High-tech paths”. In Eur-Agri-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.

4 Discussion

4.1 Contribution of alternative systems and associated strategies to sustainability and resilience

The main aim of this study was to identify sustainable and resilient alternative farming systems and associated strategies for European farming systems. Results showed that when maintaining status quo, specifically the functions “economic viability”, “attractiveness of the area” and “quality of life” were judged to be at risk. Interacting thresholds regarding these functions may lead to negative feedback loops (Paas et al., 2021a). Also resilience attributes “reasonably profitable” and “appropriately connected with actors outside of the system” were expected to develop negatively. Scientific literature often focuses on negative environmental impacts of agricultural systems (e.g., Campbell et al., 2017; Springmann et al., 2018), and policies are formulated to improve this, but deteriorating economic and social performance is of more immediate concern for stakeholders from within the farming system. While social unrest (van der Ploeg, 2020) suggests that farmers are not willing to change towards more sustainable systems as demanded by society and policy, they are mainly concerned that additional requests regarding environmental performance will render them economically unsustainable.

Desired 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 elements of different alternative systems could be combined, in others they moved in different directions, with opposite impacts on social and environmental functions. Stakeholder input provides good starting points to understand which options provide most opportunities, but it should be noted that identified alternative systems are rather adaptations than transformations. Transformations require a change in norms and values (Rotmans, 2014), while stakeholders are attached to and depend on the identity of a system, and specifically farmers largely focus on short-term economic viability (Reidsma et al., 2020a). As long as economic viability is at risk, it may however be argued that this is logical (Paas et al., 2021a). Stakeholders clearly have attention for environmental and social functions, and larger transformations may gradually evolve via a combination of incremental adaptation and ‘small wins’ (Termeer and Dewulf, 2019). Small wins are radical, but start at local level, and provide visible results and steps forward towards a shared ambition. Stakeholders may not have trust in radical transformations, but when they observe that strategies in the agronomic, economic, institutional and social domain can be combined to make a change, this may also result in changed norms and values and result in larger transformations in the longer term (De Kraker, 2017). New business models, as mentioned by multiple stakeholders in our workshops, are needed to tackle long-term challenges.

With regard to resilience attributes, strategies in the past specifically enhanced “reasonably profitable”, and to a lesser extent “builds human capital”, “socially self-organized”, “infrastructure for innovation”, “response diversity”, “functional diversity” and “production coupled with local and natural capital” (Reidsma et al., 2020a; Soriano et al., 2023).

Strategies implemented in the past, however, allowed main indicators to remain robust, but overall, resilience was judged to be low (Paas et al., 2020; Reidsma et al., 2020a). When identifying strategies that are needed to reach alternative systems, there was most focus on strengthening “coupled with local and natural capital”, both regarding production and legislation. Further potential for strengthening ecological processes lies in increasing functional diversity and creating ecologically self-regulated systems. Likewise, strengthening social processes requires social self-organization, an adequate level of connections of farming system actors with actors outside their system, and policies that simultaneously address robustness, adaptability and transformability.

Strengthening the resilience attribute “infrastructure for innovation” was important in the past and remains so for future systems. This resilience attribute is perceived by stakeholders to be particularly important for transformability (Paas et al., 2020; Reidsma et al., 2020a). Governments need to contribute to transformability by developing long-term visions and continuous and improved legislation, and also their role and of other actors in the enabling environment in investments and risk-management is crucial (Mazzucato, 2018). Translated to resilience attributes, 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) provide 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).

When assessing compatibility with future scenarios, some systems seem more resilient than others. However, none of the systems can cope with all kinds of challenges. Especially in Eur-Agri-SSP3, according to the scenario narrative, many resilience attributes are eroded. Enabling conditions for maintaining status quo and reaching desired alternative systems are thus not present in Eur-Agri-SSP3. Overall, we could, therefore, not identify “robust strategies” in the sense that they aligned with all possible scenarios (see e.g. Kok et al., 2011; van Vliet and Kok, 2015). Instead, we argue that for European farming systems, EU policies should be directed at avoiding certain scenarios, and stimulate the development towards a scenario that enables the building of local and natural resources, the development of social self-organization and technology that in turn will support the functions and resilience attributes previously mentioned. Currently, the Eur-Agri-SSPs of Mitter et al. (2020) do not describe a scenario containing all these elements, while alternative farming systems seem mostly compatible with SSP1 “Sustainable paths”. This would imply that, when taking SSP1 as a point of departure, which seems the case with the new Farm to Fork strategy, EU policies should specifically study the possibilities to strengthen institutional, social, economic and technological developments in this specific scenario. At local level, individual farming systems should be encouraged to improve their compatibility with macro-level developments. As the compatibility scores are averages of different macro-level developments (e.g. population, technology) of the narratives, farming systems may be compatible with some, but not with other developments. A strategy can thus focus on improving the compatibility with certain developments; even though at European level such a development is not compatible, at local level actors can change this, at least to some extent in their local context. The latter also refers again to the “small-wins” approach (Termeer and Dewulf, 2019): small, meaningful steps with tangible results can be energizing and lead to transformation at higher levels.

4.2 Resilience attributes

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 B). “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 I workshops (Paas et al., 2021a; Nera et al., 2020; Reidsma et al., 2020). This implied that some attributes specifically emphasized by other authors like Tittonell (2020), including “ecologically self-regulated”, “reflective and shared learning”, and “builds human capital”, were omitted. While these attributes do overlap with others, Figure 2 also showed that stakeholders do have attention for strategies related to these attributes. 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 (see also Soriano et al., 2020).

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). 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. On the other hand, a strong focus on agro-ecological transition of farming systems (e.g. Tittonell, 2020), may result in an overemphasis on diversity and redundancy, neglecting the importance of (short-term) economic viability. Farming systems are embedded in socio-technological regimes, and sustainability and resilience of farming systems also depend on the context, as also shown in the scenario compatibility analysis (section 3.5). 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. A key question is thus how institutions should govern investment in and the use of resources and capacities (Mathijs and Wauters, 2020).

4.3 Participatory assessment

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 for bottom-up innovation and change (Mosse, 1994; Timilsina et al., 2020). 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, 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. Furthermore, part of the work was executed by case study researchers, to ensure good understanding of the concepts. Lastly, different types of stakeholders were consulted in each case study, and the synthesis of results across case studies averaged out opinions of individuals or case study specific results.

In addition, in the SURE-Farm project we applied a range of qualitative and quantitative approaches to improve understanding of sustainability and resilience in 11 European farming systems (Reidsma et al., 2019; Accatino et al., 2020; Meuwissen et al., 2021). Whereas the current assessment was based on FoPIA-SURE-Farm I and II to ensure consistency, these methods were complemented with other methods and triangulation took place to assess consistency of results. For example, we used system dynamics modelling, where we combined stakeholders' perspectives with theories and empirical evidence, to check the coherency of perspectives (Herrera et al., 2022; Reidsma et al., 2020b). We also used statistical modelling to assess specific functions and resilience capacities of EU farming systems (Slijper et al., 2020; Paas et al., 2023). This mixed-methods approach allows a comprehensive insight in current and future sustainability and resilience of EU farming systems (Meuwissen et al., 2022; Meuwissen et al., 2021).

With the objective to improve sustainability and resilience of EU farming systems, the alternative systems identified in this study should not be seen as the final, but as the starting point. Alongside this bottom-up assessment, top-down assessments were performed with 'critical friends' (participants invited as experts, not as representatives of specific interests) to identify policy recommendations for more resilient farming systems (Buitenhuis et al., 2020a). 'Critical friends' are less bounded to the current situation, and their tendency towards more transformative strategies can complement the more operational focus of the local stakeholders in this study. Also more radical top-down visions of future food and farming systems (Bodirsky et al., 2022; van Zanten et al., 2023) can complement the actor-supported visions, but a participatory process is needed to make a change. The results of the current study and other approaches were used to discuss archetypical patterns identified in the various case studies and on how actions in the enabling environment tend to constrain the resilience of farming systems (Mathijs et al., 2022). Based on this, principles and recommendations for an enabling environment that fosters resilience, including transformation, were formulated. Resilience policy dialogues need to continue in the case studies, gathering all relevant actors from the farming system and its environment, based on a shared goal, information and data, a formalised and agreed time frame, and a monitoring and evaluation framework (Mathijs et al., 2022). These dialogues should be accompanied by one-to-one discussions, which are less bounded by social pressure, where ‘miracle questions’ (‘imagine that a miracle happens that results in a transformed and ideal agriculture’) can allow to think further out-of-the-box (Moore and Milkoreit, 2020; Young et al., 2023). This should pave the way towards alternative systems, which may become more transformative over time.

5 Conclusion

In this study, stakeholders identified alternative systems, aimed at improving main system functions and resilience attributes. Most alternatives suggested that stakeholders were preferring adaptations, rather than radical transformations of current systems. Incremental change may however lead to transformations in the longer-term, and the identification of alternative systems should be seen as a starting point for a transition process. In most case studies, desired alternative systems emphasizing technology, diversification and organic and/or nature friendly farming were identified. In some case studies, also systems emphasizing intensification, specialization, improved product valorization, collaboration, and an attractive countryside were options that can increase sustainability and resilience.

The resilience of current farming systems is low, as strategies have been mainly focused on strengthening the economic sustainability dimension and robustness resilience capacity. To make a transition to alternative systems and improved resilience, strategies need to simultaneously reinforce economic (less focused on scale enlargement and intensification, but more on developing new business models), environmental (e.g., soil quality, varieties adapted to local climatic conditions, reducing inputs, improving circularity), institutional (e.g., regulations, rewarding the delivery of public goods) and social (e.g., improving the level of connections of farming system actors with actors outside their system) sustainability dimensions. Maintaining profitability remains important, but it should not get the strong focus as it currently gets in most farming systems.

Different alternative systems will thrive under different enabling environments, and therefore all may be feasible options, but this depends on future scenarios. Most alternatives mainly thrive in the scenario 'agriculture on sustainable paths', while being specifically vulnerable in 'agriculture on separated paths'. Flexibility is required for farming system actors to adjust the strategies according to the nature of future conditions. Simultaneously, for thriving European farming systems, EU policies should be directed at "unfolding" the "agriculture on sustainable paths" scenario while stimulating macro-level institutional, social, economic and technological developments that seem lacking in this specific scenario. Farmers need to be supported by other actors in the farming systems and the enabling environment, in order to realize more sustainable and resilient European farming systems.

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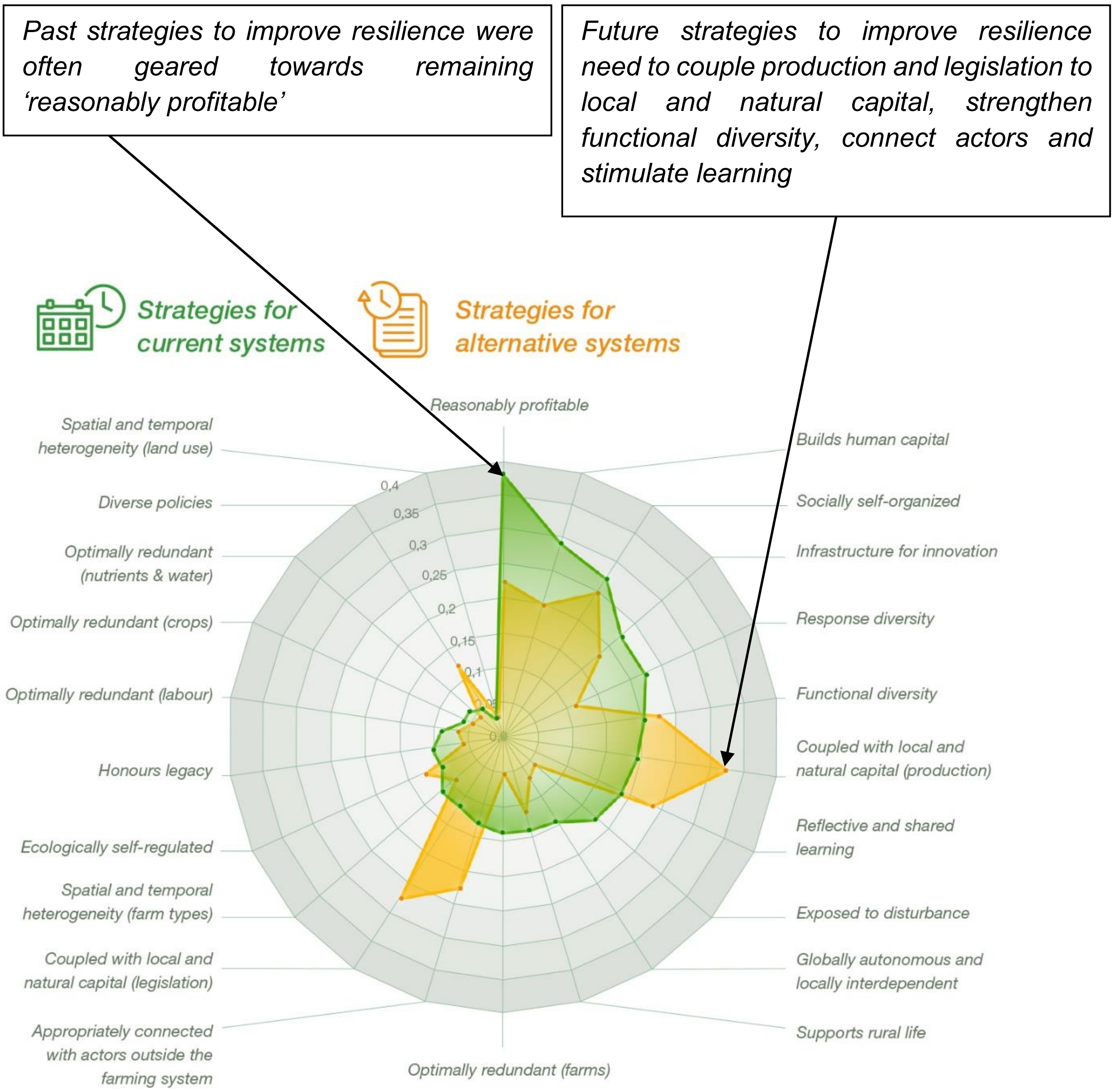
Alternative systems and strategies to improve future sustainability and resilience of farming systems across Europe: from adaptation to transformation

Highlights

- Backcasting was used to identify alternative European farming systems supported by stakeholders
- Low economic viability limited farming system actors to improve sustainability and resilience
- To strengthen resilience, production and legislation need to be coupled to local and natural capital
- Desired alternative systems are diverse but only compatible with the 'sustainable paths' scenario
- To get stakeholders along, incremental adaptation rather than radical transformation should be sought

Graphical abstract



Abstract

According to stakeholders, many European farming 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). To accelerate a transition process towards sustainable and resilient agriculture, this ~~paper~~ study aimed~~s~~ to identify actor-supported alternative systems across 10 European farming systems, and to identify associated future strategies that contribute to strengthening resilience attributes, using a backcasting approach. ~~It~~ This paper synthesizes 1) the participatory identification of desired alternative systems and their expected performance on sustainability and resilience~~ (stakeholder-based assessment)~~, 2) the participatory identification of strategies to realize those alternative systems~~ (stakeholder-based assessment)~~, 3) the contribution of identified past and future strategies to 22 resilience attributes ~~(researcher-based assessment)~~, and 4) the compatibility of the status quo and alternative systems with different future scenarios, the Eur-Agri-SSPs~~ (researcher-based assessment)~~. Many ~~desired~~ identified alternative systems emphasized technology, diversification and organic and/or nature friendly farming, while ~~for~~ in some farming systems also intensification, specialization, better product valorization, collaboration, and creating an attractive countryside could increase sustainability and resilience. Low economic viability limited farming system actors to pay attention to environmental and social functions. Further, most alternative systems were adaptations rather than transformations. ~~As main products are part of the identity of the farming system,~~ Many stakeholders had difficulty to envisage systems without the main~~se~~ products (e.g., starch potato in NL-Arable, sheep in ES-Sheep and h~~H~~azelnut in IT-H~~h~~azelnut), but in few cases transformative systems were designed (e.g. local organic farming in PL-Horticulture and RO-M~~m~~ixed). Sustainability and resilience can be enhanced when alternative systems and strategies are combined, thereby improving multiple functions and attributes at once. In particular, production and legislation need to be coupled to local and

natural capital. ~~Desired~~ Identified alternative systems seem only compatible with Eur-Agri-SSP1 ‘agriculture on sustainable paths’. This requires policies at EU-level that stimulate macro-level social, institutional, economic, and technological developments that strengthen this scenario. We conclude that t~~T~~o get stakeholders along, incremental adaptation ~~leading to transformation~~ rather than radical transformation should be sought. The identification of ~~Envisaged~~ alternative systems ~~are~~ is only a start for the transition process. Their analysis, along with the strategies identified, need to trigger the involvement of farmers and other ‘enabling actors’ inside and outside the farming systems~~,~~ ~~alongside farmers,~~ to make a change, ~~leading to transformation~~and where needed, systems can evolve into more transformative systems.

~~Farmers need to be supported by other actors, inside and outside the farming systems, to make a change, and the envisaged systems are only a start for a transition process~~

Keywords: resilience, sustainable development, backcasting, stakeholders, participatory, ~~agricultural systems,~~ scenarios

1 Introduction

Farming systems in Europe are increasingly challenged by economic, environmental, social, and institutional changes (Meuwissen et al., 2020). 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 recent years, resulting in yield reductions. In addition, 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 and Reidsma, 2021; 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 the resulting lock-downs caused specific shocks, notably for systems relying on catering, export and agritourism (Meuwissen et al., 2021; Savary et al., 2020). All these shocks and stresses affect the sustainability and resilience of European 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. General action points for initiating transformation are listed, but more knowledge is needed to identify which specific (and local) actions lead to more sustainable and resilient agricultural systems. In addition, knowledge is needed on which actions correspond with the wishes, capacities and willingness of farming system actors, as they are key in initiating actions on the ground.

In the SURE-Farm project, we developed a framework to assess the resilience of farming systems (Meuwissen et al., 2019), which can be used for the purpose of identifying sustainability and resilience enhancing strategies. 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 resilience 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.

Three resilience capacities can be 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). Accordingly, adaptation is a change in the composition of inputs, production, marketing and risk management but without changing the structures and feedback mechanisms of the farming system, while transformation is a change in the internal structure and feedback mechanism of the farming system into a desired direction in response to either severe shocks or enduring stress that make business as usual impossible. Deliberate transformation requires resilience thinking, first in assessing the relative merits of the current versus alternative systems in potentially more favourable stability domains (i.e., a domain where a system is robust within certain thresholds of control variables), and second in fostering resilience of the new development trajectory (i.e., towards an alternative, transformed system) and the new basin of attraction (i.e., a system with a more sustainable stability domain) (Folke et al., 2010).

Based on the framework by Meuwissen et al. (2019) a range of quantitative and qualitative methods was employed to investigate sustainability and resilience in 11 European farming systems (Meuwissen et al., 2022; Meuwissen et al., 2021). 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 analyse current systems based on statistical data (Dardonville et al., 2021; Reidsma et al., 2010; Slijper et al., 2020), and to simulate the impact of specific scenarios on specific indicators (e.g., Herrera et al., 2022), 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 a rural area for residents and visitors is difficult to capture with quantitative indicators). In addition, to assess resilience, dynamics of multiple processes need to be investigated simultaneously (Kinzig et al., 2006; Walker and Salt, 2012). 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., 2010). Qualitative approaches are needed to understand the dynamics of farms and ~~can partly~~to address the above-mentioned issues (Darnhofer, 2014). 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). In addition, in order to follow-up on an assessment and allow for a transition process, farming system actors (stakeholders and the enabling environment; see Meuwissen et al., 2019) need to be part of the assessment (Quist and Vergragt, 2006). Hence, we first assessed sustainability and resilience of *current* European farming systems with a structured participatory method (Paas et al., 2020; Reidsma et al., 2020a), and next, we addressed sustainability and resilience of *future* farming systems in collaboration with relevant actors (Paas et al., 2021a; Paas et al., 2021b).

According to stakeholders in the first round of workshops in the selected European farming systems, sustainability and resilience of current systems is low (Paas et al., 2020; Reidsma et al., 2020a). In the first part of the second round of workshops, on future systems, it was concluded that many of the current 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) (Paas et al., 2021a). A quantitative modelling study confirmed closeness to critical thresholds for the Dutch case study, and showed that only actively implementing strategies allowed the system to remain resilient (Herrera et al., 2022). However, across Europe strategies have, so far, mainly focussed on robustness, and lack attention for adaptability and transformability (Buitenhuis et al., 2020b; Paas et al., 2020; Reidsma et al., 2020a).

Alternative systems and associated strategies are thus needed. These were addressed in the second part of the workshops on future systems, and are the focus of this paper. The aim of this paper is to identify actor-supported alternative systems across 10 European farming systems that contribute to sustainability and resilience, and to identify associated future strategies that contribute to strengthening resilience attributes. In addition, the compatibility of the *status quo* and alternative systems with the developments in different future scenarios is assessed, as resilience depends both on internal and external factors.

2 Material and methods

2.1 Participatory assessment of resilience and sustainability of farming systems

Case study farming systems covered different sectors, farm types, products and challenges in European agriculture (Table 1; Appendix A; Bijttebier et al., 2018; Meuwissen et al., 2022). All farming systems cover a region within a country, but the scale differs per case study.

Table 1. The 10 case study farming systems, including date and number of participants in the FoPIA-SURE-Farm II workshops.

Acronym	Specialization, location	Date	Total	Farmer	Govern-ment	Industry	NGO	Agricultural advice	Research	Finance	Other
BG-Arable	Large-scale arable farming, Bulgaria	16/01/2020	19	8	5	1	2	3			
NL-Arable	Intensive arable farming, the Veenkoloniën region in the Netherlands	10/12/2019	22	8	3	2	2		3	2	2
UK-Arable	Arable farming, East of England in the United Kingdom	15/01/2020	5		1		2	2			
DE-Arable&Mixed	Large-scale corporate arable farming with additional livestock activities, East Germany	06/02/2020	15	5	4	1	1	1	1		
RO-Mixed	Small-scale mixed farming, North-East Romania	12/03/2020	16	6	2	3			5		
FR-Beef	Extensive beef cattle systems, the Massif Central, France	Desk study	-								
ES-Sheep	Extensive sheep farming, Northeast Spain	14/02/2020	18	7	4	1		3	3		
SE-Poultry	High-value egg and broiler systems, Southern Sweden	31/01/2020 & 03/02/2020	9	5		3					1
IT-Hazelnut	Small-scale hazelnut production, Central Italy	21/01/2020	14	5	2	1	2	3	1		
PL-Horticulture	Fruit and vegetable farming, the Mazovian region in Poland	29/11/2019	12	7	1		1	3			

Based on the resilience framework, a Framework of Participatory Impact Assessment for Sustainable and Resilient EU farming systems (FoPIA-SURE-Farm) was developed. FoPIA-SURE-Farm includes two series of participatory workshops, both including a preparation and evaluation phase by researchers, focussing on current (FoPIA-SURE-Farm I) and future (FoPIA-SURE-Farm II) sustainability and resilience. This paper synthesizes workshop results from the second half of FoPIA-SURE-Farm II for 10 European farming systems. These results build on previous steps from the FoPIA-SURE-Farm I approach. These previous steps are briefly described in the two following paragraphs. After that, the methodological steps are described that lead to the results presented in this paper.

FoPIA-SURE-Farm I (Nera et al., 2020; Paas et al., 2020; Reidsma et al., 2020a), was conducted in the 10 case studies presented in (Table 1) and a case study on dairy farming in Flanders, Belgium. In each case study, one workshop of around six hours was held between November 2018 and March 2019. 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 (Paas et al., 2020). In brief, the workshops focused 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 past 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 resilience attributes and their potential contribution to the robustness, adaptability and transformability of the farming system.

In FoPIA-SURE-Farm II (Paas et al., 2021b) a, a workshop of around four hours was held between November 2019 and March 2020 in 9 case studies, and in 1 case study (FR-Beef) a desk study was performed, as the COVID-19 crisis prevented the realization of the workshop. In the desk study, inputs from stakeholders and experts, based on earlier work and literature, were considered. Only specific results from this case study are included. A desk study was also performed in the aforementioned Belgian case study, but this case is excluded from the current paper as it focused on the status quo only. The number of participants ranged between 5 and 22, with a total of 128 participants~~.~~ (Table 1; Paas et al., 2021a). The first half of the workshop was focused on forecasting in relation to maintaining the status quo and system decline in case critical thresholds would be exceeded, and results for the 10 European farming systems and the one in Belgium are described in Paas et al. (2021a). This forecasting approach included an assessment of: 1) the development of current systems; 2) identification of critical thresholds whose exceedance can lead to large and permanent system change; 3) an assessment of the developments when critical thresholds are exceeded. These steps build on FoPIA-SURE-Farm I, as the previously identified most important functions, challenges and resilience attributes were considered for this assessment.

The second half of the workshop was focused on alternative systems and strategies to achieve these, using a backcasting approach (Figure 1; this paper). The essence of backcasting consists of ~~generating~~ creating desirable sustainable future visions, followed by looking back at how these desirable futures can be achieved, by ~~and turning these, through backcasting analysis, design activities and analysis, into follow-up agendas,~~ planning ~~for actions and~~ the ~~realis~~ation ~~of ing~~ follow-up activities and developing strategies leading to that desirable future (Quist and Vergragt, 2006). The backcasting approach included the remaining steps of FoPIA-SURE-Farm II: 4) participatory identification of desired alternative systems towards 2030 and their expected improved performance of sustainability and resilience; 5a) participatory identification of strategies to achieve those alternative systems. The evaluation phase included 6) an assessment by researchers on the compatibility of alternative systems with the developments of exogenous factors as projected in different future scenarios (for more detail, see section 2.2).

Methods and results of all six steps of FoPIA-SURE-Farm II are described in detail for extensive sheep farming in Huesca, Spain, in Paas et al. (2021b)~~;~~. Paas et al. (2021b) present results from the first part across European farming systems, providing forecasts for current systems.~~; and i~~ In this paper, we will synthesize results from the second part across European farming systems, backcasting alternative systems (for details, see Accatino et al., 2020). In the evaluation phase, we added 5b) an assessment by researchers of the contribution of the identified past and future strategies to 22 resilience attributes, to assess and synthesize their impact~~s~~ on resilience ~~our findings~~ across case studies.~~.~~ All methodological steps are further explained in the next section. General guidelines were followed, but slight deviations were made in specific case studies depending on the needs of the stakeholders.

2.2 Backcasting to design and evaluate alternative systems and strategies

Starting with step 4 of FoPIA-SURE-Farm II, we present the identification of alternative systems for the future (Figure 1). All participants in the workshops were asked individually to envisage one or more alternative systems they desired towards 2030 if challenges, functions and/or resilience attributes would cross critical thresholds. 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 common alternative systems. Suggestions by individuals were grouped into 2-4 alternative systems. These were considered to be potential future systems, along with maintaining status quo, and system decline (when essential requirements are not met), which serve as a reference.

For the cross-case study comparison, alternative systems were categorized according to the most important direction that an alternative system is taking (e.g., specialization), 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. The categories that came forward in this study are also not exhaustive in the sense that they do not cover all directions that alternative systems can take.

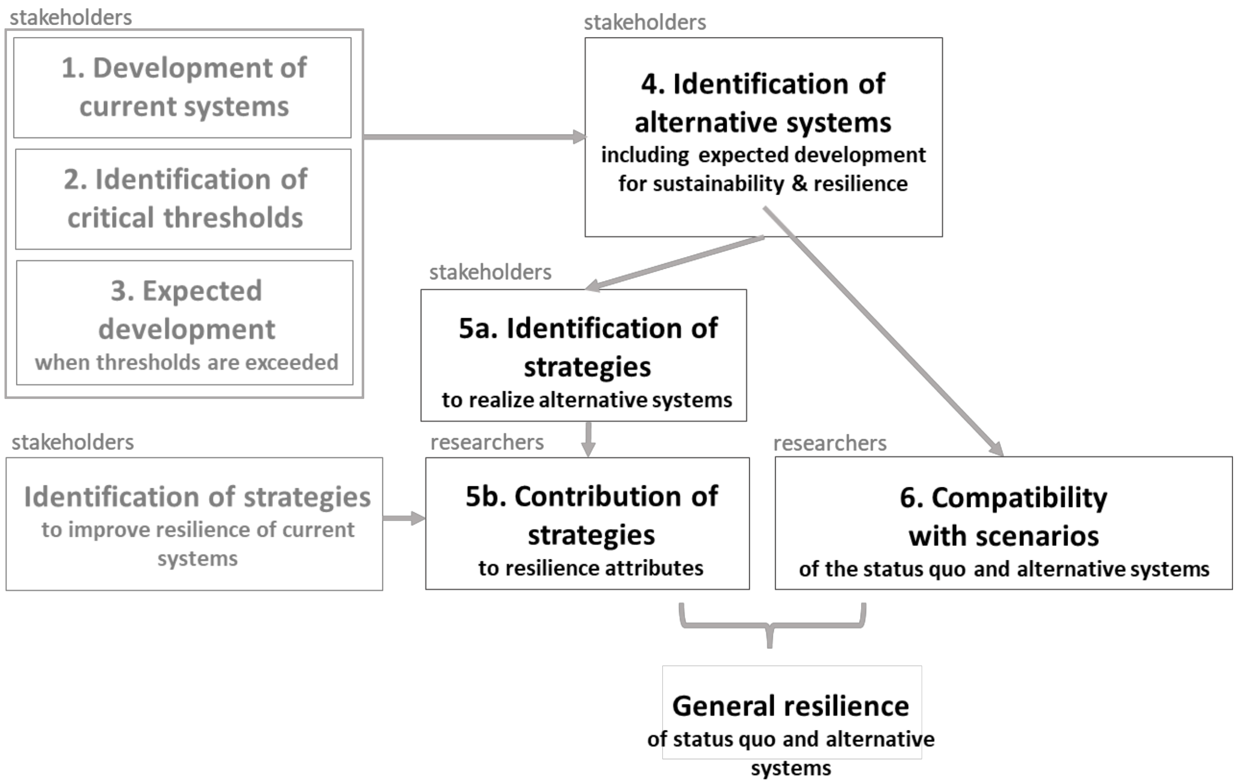


Figure 1. Steps in the backcasting approach of FoPIA-SURE-Farm II to identify alternative systems that contribute to sustainability and resilience, and to identify associated strategies and developments in future scenarios that contribute to general resilience. Step 4-6 (in black) refer to backcasting and are addressed in this paper. Step 1-3 (in grey) refer to the forecasting part of FoPIA-SURE-Farm II, which serves as input for the assessment, together with 'Identification of strategies to improve resilience of current systems' coming from FoPIA-SURE-Farm I. Step 1-5a are stakeholder-based, and step 5b and 6 are researcher-based.

Subsequently, stakeholders were divided in small groups and within each group one alternative system was discussed (or in subsequent sessions when the number of participants was too small) with regard to main function indicators, resilience attributes and enabling conditions. A selected set (based on FoPIA-SURE-Farm I) of main function indicators and resilience attributes was discussed per case study (see Table SM1.5 of Paas et al., 2021b) as critical system changes are expected to be determined by a small set of key variables (Kinzig et al., 2006). Developments were classified as strongly negative (-2), moderately negative (-1), no impact (0), moderately positive (+1) and strongly positive developments (+2). For the synthesis across case studies, the minimum and maximum of expected developments per function (eight in total) and resilience attribute (13 in total) were evaluated and translated into arrows with the same meaning. These were compared with the average expected developments for the status quo and system decline (Paas et al., 2021a).

Step 5a was the identification of strategies that would be needed to reach the alternative systems and to improve resilience. ~~.~~This was done in the same groups discussing alternative systems. These future strategies were classified as agronomic, economic, social or institutional, and listed along with strategies that were applied in the past to ~~cope with main challenges~~improve resilience, as identified in FoPIA-SURE-Farm I (Paas et al., 2019). In some case studies, the strategies identified in FoPIA-SURE-Farm I were complemented with strategies identified using other SURE-Farm approaches (e.g. Reidsma et al., 2019; Soriano et al., 2020).

A farming system can be resilient to specific challenges (specified resilience), and strategies can be implemented to deal with such challenges, but this does not necessarily imply that the farming system is capable to deal with the unknown, uncertainty and surprise (general resilience). General resilience can be judged based on the presence of resilience attributes (Meuwissen et al., 2019; Cabell and Oelofse, 2012). An additional step 5b was therefore included to assess the impact of strategies on general resilience. After the workshops, researchers assessed the contribution (either yes or no) of the identified past and future strategies to 22 resilience attributes (see Appendix B for full description). In the assessments with stakeholders, 13 out of these 22 were selected to be discussed, but researchers were assumed to be able to address all 22, allowing ~~both a more holistic picture and a judgement regarding the completeness of the selected list~~to assess which ones from the full list were most important, (also in comparison to the selected 13). 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 B). The 22 attributes are associated to the 5 general resilience principles (system reserves, tightness of feedbacks, diversity, modularity and openness; Appendix B; Meuwissen et al., 2019). The first and last author of this paper 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~~ and last authors. Results were synthesized based on the relative share of strategies contributing to a resilience attribute, where the contribution of future strategies to reach alternative systems was compared with (past) strategies implemented for current systems.

General resilience also relates to the compatibility of farming systems with ~~different future scenarios~~external factors. Some resilience attributes relate to the farming system itself, and some to the enabling environment, and the latter is influenced by scenario narratives. Mitter et al. (2019, 2020) developed five scenarios for European agriculture and food systems, called Eur-Agri-SSPs. These scenarios are plausible and internally consistent views of the future and are in line with the Shared Socio-Economic Pathways (SSPs) as developed for the climate change research community. They ~~and~~ include Eur-Agri-SSP1 – Agriculture on sustainable paths, Eur-Agri-SSP2 – Agriculture on established paths, Eur-Agri-SSP3 – Agriculture on separated paths, Eur-Agri-SSP4 – Agriculture on unequal paths, and Eur-Agri-SSP5 – Agriculture on high-tech paths. Table 3 of Mitter et al. (2020) presents storyline elements and directions of change for the five Eur-Agri-SSPs (see also: https://eur-agri-ssps.boku.ac.at/eur-agri-ssps-2/).

In step 6 of FoPIA-SURE-Farm II, the compatibility of the future farming systems (status quo and alternative systems) with the directions of change of the storyline elements as projected in these five Eur-Agri-SSPs was assessed. For each future farming system ~~(status quo and~~

alternative systems), case study partners indicated how important an increase in the scenario elements (related to the sections 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 scenario elements were based on Mitter et al. (2020), with -1, 0 and 1 indicating negative, no and positive changes, respectively. Multiplication of the importance of developments for future systems with expected developments of scenario elements was used as an approximation for compatibility. Final compatibility scores per future system per scenario 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 to 0 weak incompatibility, 0 to 0.33 weak compatibility, 0.33 to 0.66 moderate compatibility, and 0.66 to 1 strong compatibility. An example for ES-Sheep is presented in Paas et al (2021c). For the comparison across case studies, compatibility scores per Eur-Agri-SSP were averaged per category of the alternative systems.

3 Results

3.1 Alternative farming systems

Many desired alternative systems are adaptations rather than transformations of current systems (Table 2; see Appendix A for details). For example, in NL-Arable, starch potato production is at the core of the farming system, and stakeholders had difficulties identifying alternatives without starch potatoes. Similarly, in ES-Sheep, alternatives identified what is needed to keep sheep farming. Integration and diversification were emphasized in many alternatives, but changes in the main products were not envisaged. Some systems can be considered transformative considering the change in intensity of production. For example, the 'desirable system' in UK-Arable is supposed to be regenerative. The local organic farming system in PL-Horticulture is a real transformation, as it changes the whole food system.

The alternative systems could broadly be grouped in eight categories 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, FR-Beef and PL-Horticulture, alternative systems focused on intensification or specialization were seen as relevant and viable options. Also in SE-Poultry, further intensification was considered as an option. Many case studies considered alternatives which focused on technology development, where generally new technologies should also allow for improving the maintenance of natural resources and biodiversity (e.g. precision agriculture in NL-Arable, high-tech extensive production in ES-Sheep, robots in SE-Poultry). 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, such as food production and maintaining natural resources. 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). In many case studies they~~re~~ were seen as ambitious and subject to many enabling conditions.

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 (BG-Arable, DE-Arable&Mixed, NL-Arable, SE-Poultry, IT-Hazelnut, ES-Sheep), and/or over time at the farming system level (e.g., the likely system may evolve into the desired system in UK-Arable).

Table 2. 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.~~

	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)**
Intensifica-tion				Intensification		Semi-intensive		Large farms			3
Specializa-tion					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
Collabora-tion	Collaboration	Collaboration & water			Cooperation / multifunctio-nality						3
Attractive countryside				Better societal appreciation			Development of tourism			Sustained demand (high and stable prices)	3
Diversifica-tion	Crop diversifi-cation	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 FR-Beef, a desk study with researchers was conducted instead of a workshop with stakeholders.
[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.

3.2 Development of future systems

Future systems include maintenance of the *status quo*, system decline when critical thresholds are exceeded and the desired alternative systems. ~~In this paper w~~We use the function and attribute development under continued status quo and system decline, which are described in Paas et al. (2021b), as points of reference.~~.~~ ~~For the purpose of reflecting on the results, a~~A summary is provided in the remainder of this paragraph. When maintaining status quo under the current challenges, 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, for the continued status quo, no large negative changes 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.

We note that in farming systems with current low economic performance (i.e. PL-Horticulture, ES-Sheep, BG-Arable, SE-Poultry), there was a larger tendency to identify alternative systems that mainly focus on improving economic functions, while there was increased attention for improving social functions when economic performance was perceived to be higher (i.e. RO-Mixed, NL-Arable, IT-Hazelnut) (see Appendix C for details). Focussing on improving economic performance, often seems to be at the expense of social and environmental functions.

Minimum and maximum ~~positive~~ developments of farming system functions in alternative systems indicate that for most functions at ~~most~~ best moderate improvements are expected (Table 3; Appendix C). 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” (evaluated once) and “biodiversity & habitat” (evaluated four times), the average maximum development is expected to be strongly positive, while the average minimum development is expected to be negative and stable, respectively. This indicates that for these functions, alternative systems seem to take different directions, and stakeholders foresee trade-offs.

Under alternative systems, “food production” is perceived to at least not 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 continue in the “likely” alternative system. In multiple case studies, some alternative systems resulted in negative developments for “food production” (BG-Arable), “bio-based resources” (DE-Arable&Mixed, RO-Mixed), “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.

Table 3. 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 (↓) **and brown** imply strong negative, down-right (↘) **and orange** moderate negative, straight (→) stable, right-up (↗) and light green moderate positive, and up (↑) **and dark green** strong positive developments, with others in-between.

			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] Results for FR-Beef are not included in this table.

Minimum and maximum 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 evaluated 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 multiple alternative systems.

3.3 Identification of past and future strategies

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

Agronomic strategies included diversification, implementation of more technology, and improved knowledge and research on crops and livestock (NL-Arable, ES-Sheep, SE-Poultry, DE-Arable&Mixed, RO-Mixed). In many cases, these were strategies already employed by part of the farms, which can only be up-scaled in combination with economic, institutional and social strategies.

While in the past, strategies to remain resilient focused on the economic domain, when envisaging future strategies attention shifted to other domains. Strategies that had been important in the past, such as increasing farm size and intensity, do not contribute to most alternative systems. However, in many case studies, economic strategies such as diversification of income sources (ES-Sheep, FR-Beef, RO-Mixed, UK-Arable) remained ~~relevant~~ important in at least one of the alternative systems. Economic strategies thus remained relevant, but the nature changed. For example, in NL-Arable, for three out of four alternative systems economic strategies were identified, 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 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) and financial support in general (PL-Horticulture, IT-Hazelnut, RO-Mixed).

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. Important strategies in the social domain included cooperation and/or knowledge sharing among farming system actors (in a value chain and/or cooperative) (all case studies having socially oriented strategies), and 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).

Alternative systems cannot be reached by implementing one strategy, but various agronomic, economic, institutional and social strategies need to be combined, and implemented by different actors (see Appendix D for required strategies per alternative system).

3.4 How do past and future strategies impact resilience attributes?

Past strategies to cope with specific challenges and improve resilience were often geared towards maintaining profitability, such as intensification and scale enlargement, and to a lesser extent towards other resilience attributes, like building human capital, social self-organization, facilitating infrastructure for innovation, enhancing response and functional diversity, and coupling production with local and natural capital (Figure 2; see Appendix B for explanation of resilience attributes). For these resilience attributes, negative developments were expected when maintaining status quo (Table 3), while they were considered important for resilience capacities (Paas et al, 2019; Reidsma et al. 2020). There has been limited attention for improving redundancy and spatial and temporal heterogeneity.

In order to reach more sustainable and resilient future systems, stakeholders argue that maintaining profitability remains important, but specifically more attention is needed for strategies coupling production and legislation with local and natural capital (Figure 2). Strategies to improve these resilience attributes include improving soil quality, improving circularity, reducing inputs, using varieties adapted to local climatic conditions, local branding, and policies that support these production practices. Further potential for strengthening ecological processes lies in increasing functional diversity (e.g. diversification of varieties, crops, livestock, markets, on-farm and off-farm activities) and creating ecologically self-regulated systems (e.g. alternative fertilization, reintroducing livestock; often also considered under coupled with local and natural capital). Likewise, strengthening social processes requires social self-organization (e.g. improve culture of trust, creation of shepherd schools, creation and promotion of a locally recognized brand), an adequate level of connections of farming system actors with actors outside their system, and diverse policies that simultaneously address robustness, adaptability and transformability.

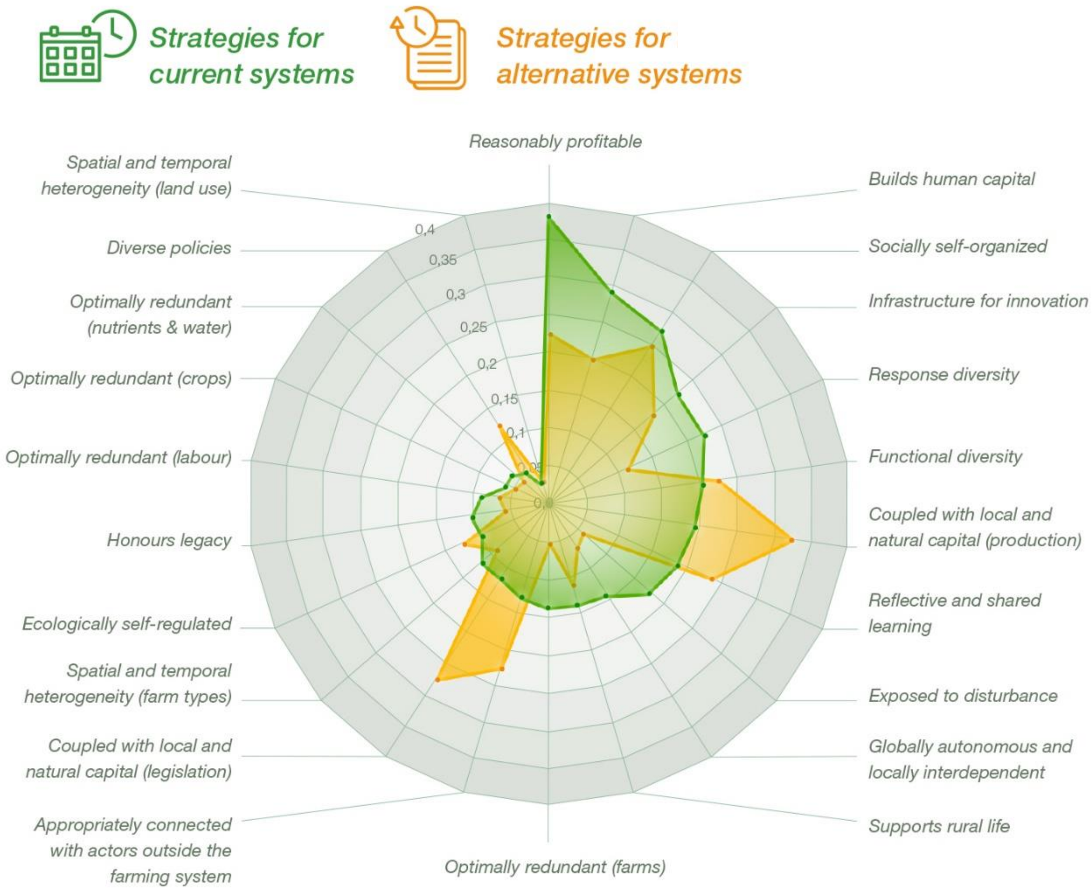


Figure 2. The contribution to resilience attributes of the identified strategies implemented and proposed in farming systems. The green line shows the ratio of (past) strategies implemented for current systems contributing to an attribute, and the orange line the ratio of future strategies for alternative systems contributing to an attribute. Attributes are ordered, starting with the attribute to which most past strategies contributed.

3.5 Compatibility of farming systems with future scenarios

Although different strategies are needed for different alternative systems, alternative systems generally thrive in the same scenario. Most future systems, including maintaining the status quo, are most compatible with Eur-Agri-SSP1 “Sustainable paths” (Table 4; Appendix E). This is mainly due to favourable developments regarding policies and institutions and technology, which are environment-focused (e.g., agri-environmental payments increase), corresponding with enabling conditions and strategies for most future systems (Appendix E). 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. For arable systems, the need for improving soil quality also explains lesser compatibility with other Eur-Agri-SSPs, where maintenance of natural resources is expected to stay stable or even decline. 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. The most compatible development would be towards alternative systems primarily driven by organic / nature friendly production under Eur-Agri-SSP1, but also product valorization and intensification seem to be very compatible with this scenario.

Table 4. Average compatibility of alternative system categories with Eur-Agri-SSPs. With values -1 to -0.66: strong incompatibility, -0.66 to -0.33: moderate incompatibility, -0.33 to 0: weak incompatibility, 0 to 0.33 weak compatibility, 0.33 to 0.66: moderate compatibility, and 0.66 to 1: strong compatibility. Colours reflect compatibility categories. Aggregated results from nine case studies.

		Average compatibility score with Eur-Agri-SSPs				
Category future systems	Future systems [#]	SSP1 "Sustain-able"	SSP2 "Established"	SSP3 "Separated"	SSP4 "Unequal"	SSP5 "High-tech"
Status quo	9	0.56	0.31	-0.60	0.15	0.29
Intensification	3	0.63	0.45	-0.32	0.20	0.27
Specialization	2	0.50	0.35	-0.67	0.24	0.37
Technology	6	0.61	0.30	-0.52	0.21	0.25
Product valorization	2	0.68	0.26	-0.79	0.00	0.23
Collaboration	3	0.63	0.26	-0.75	0.16	0.24
Attractive countryside	2	0.50	0.43	-0.62	0.26	0.52
Diversification	5	0.69	0.24	-0.50	0.07	0.14
Organic / nature friendly	6	0.71	0.36	-0.74	0.10	0.21
Average[1]		**0.62**	**0.32**	**-0.60**	**0.15**	**0.26**

[1] *Results for FR-Beef are not included in this table.*

With regard to environmental developments needed for at least maintaining the status quo, it becomes clear that Eur-Agri-SSP2 "Established paths" will not bring the developments that are needed to avoid exceeding environmental thresholds in the arable systems (e.g., resource depletion will continue). Still, supported by generally positive developments in the economy, policies and institutions (e.g., international trade agreements improve) and technology (e.g., technology uptake in agriculture improves), most case studies are weakly compatible with Eur-Agri-SSP2. However, for case studies where further intensification was seen as a possibility for the future (ES-Sheep, SE-Poultry; but also RO-Mixed), Eur-Agri-SSP2 seems to be moderately compatible, while also the systems emphasizing an attractive countryside (specifically in IT-Hazelnut) are moderately compatible.

In Eur-Agri-SSP3 “Separated paths”, 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. Eur-Agri-SSP3 seems, therefore, most incompatible with most future systems in all case studies, especially because many farming systems currently produce for international markets and/or depend on technology and maintenance of remaining natural resources. SE-Poultry is an exception to this, because of the current experienced mismatch between 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 (under the condition that technology and feed are also locally produced). 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.

Eur-Agri-SSP4 “Inequality paths” shows a mix of positive and negative developments. Storyline elements in relation to population, such as rural-urban linkages are expected to decrease while technology levels are expected to go up. Elements related to economy and policies and institutions are showing both positive and negative developments. In Eur-Agri-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 Eur-Agri-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 Eur-Agri-SSP5 “High-tech paths”. In Eur-Agri-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.

4 Discussion

4.1 Contribution of alternative systems and associated strategies to sustainability and resilience

The main aim of this study was to identify sustainable and resilient alternative farming systems and associated strategies for European farming systems. Results showed that when maintaining status quo, specifically the functions “economic viability”, “attractiveness of the area” and “quality of life” were judged to be at risk. Interacting thresholds regarding these functions may lead to negative feedback loops (Paas et al., 2021a). Also resilience attributes “reasonably profitable” and “appropriately connected with actors outside of the system” were expected to develop negatively. Scientific literature often focuses on negative environmental impacts of agricultural systems (e.g., Campbell et al., 2017; Springmann et al., 2018), and policies are formulated to improve this, but deteriorating economic and social performance is of more immediate concern for stakeholders from within the farming system. While social unrest (van der Ploeg, 2020) suggests that farmers are not willing to change towards more sustainable systems as demanded by society and policy, they are mainly concerned that additional requests regarding environmental performance will render them economically unsustainable.

Desired 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 elements of different alternative systems could be combined, in others they moved in different directions, with opposite impacts on social and environmental functions. Stakeholder input provides good starting points to understand which options provide most opportunities, but it should be noted that identified alternative systems are rather adaptations than transformations. Transformations require a change in norms and values (Rotmans, 2014), while stakeholders are attached to and depend on the identity of a system, and specifically farmers largely focus on short-term economic viability (Reidsma et al., 2020a). As long as economic viability is at risk, it may however be argued that this is logical (Paas et al., 2021a). Stakeholders clearly have attention for environmental and social functions, and larger transformations may gradually evolve via a combination of incremental adaptation and 'small wins' (Termeer and Dewulf, 2019). Small wins are radical, but start at local level, and provide visible results and steps forward towards a shared ambition. Stakeholders may not have trust in radical transformations, but when they observe that strategies in the agronomic, economic, institutional and social domain can be combined to make ~~incremental adaptations~~a change, this may also result in changed norms and values and result in larger transformations in the longer term (De Kraker, 2017). New business models, as mentioned by multiple stakeholders in our workshops, are needed to tackle long-term challenges.

With regard to resilience attributes, strategies in the past specifically enhanced "reasonably profitable", and to a lesser extent "builds human capital", "socially self-organized", "infrastructure for innovation", "response diversity", "functional diversity" and "production coupled with local and natural capital"~~. This result is in line with Soriano et al.~~ (Reidsma et al., 2020a; Soriano et al., 2023). ~~who found that according to stakeholders in a different set of focus groups, the actors in farming systems in Europe have contributed to the resilience attributes "builds human capital", "response diversity", "socially self-organized and "reflecting and shared learning" by implementing strategies to deal with challenges threatening farming systems.~~

Strategies implemented in the past, however, allowed main indicators to remain robust, but overall, resilience was judged to be low (Paas et al., 2020; Reidsma et al., 2020a). When identifying strategies that are needed to reach alternative systems, there was most focus on strengthening "coupled with local and natural capital", both regarding production and legislation. Further potential for strengthening ecological processes lies in increasing functional diversity and creating ecologically self-regulated systems. Likewise, strengthening social processes requires social self-organization, an adequate level of connections of farming system actors with actors outside their system, and policies that simultaneously address robustness, adaptability and transformability.

Strengthening the resilience attribute “infrastructure for innovation” was important in the past and remains so for future systems. This resilience attribute is perceived by stakeholders to be particularly important for transformability (Paas et al., 2020; Reidsma et al., 2020a). ~~While~~ ~~g~~Governments need to contribute to transformability by developing long-term visions and continuous and improved legislation, ~~it has been suggested that the role of the enabling environment~~and also their role and of other actors in the enabling environment in investments and risk-management is crucial (Mazzucato, 2018)~~(Mazzucato, 2018)~~. Translated to resilience attributes, ~~G~~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) provide 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).

When assessing compatibility with future scenarios, some systems seem more resilient than others. However, none of the systems can cope with all kinds of challenges. Especially in Eur-Agri-SSP3, according to the scenario narrative, many resilience attributes are eroded. Enabling conditions for maintaining status quo and reaching desired alternative systems are thus not present in Eur-Agri-SSP3. Overall, we could, therefore, not identify “robust strategies” in the sense that they aligned with all possible scenarios (see e.g. Kok et al., 2011; van Vliet and Kok, 2015). Instead, we argue that for European farming systems, EU policies should be directed at avoiding certain scenarios, and stimulate the development towards a scenario that enables the building of local and natural resources, the development of social self-organization and technology that in turn will support the functions and resilience attributes previously mentioned. ~~t.~~ Currently, the Eur-Agri-SSPs of Mitter et al. (2020) do not describe a scenario containing all these elements, while alternative farming systems seem mostly compatible with SSP1 “Sustainable paths”. This would imply that, when taking SSP1 as a point of departure, which seems the case with the new Farm to Fork strategy, EU policies should specifically study the possibilities to strengthen institutional, social, economic and technological developments in this specific scenario. At local level, individual farming systems should be encouraged to improve their compatibility with macro-level developments. As the compatibility scores are averages of different macro-level developments (e.g. population, technology) of the narratives, farming systems may be compatible with some, but not with other developments. A strategy can thus focus on improving the compatibility with certain developments; even though at European level such a development is not compatible, at local level actors can change this, at least to some extent in their local context. The latter also refers again to the “small-wins” approach (Termeer and Dewulf, 2019): small, meaningful steps with tangible results can be energizing and lead to transformation at higher levels.

4.2 Resilience attributes

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 B). “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 I workshops (Paas et al., 2021a; Nera et al., 2020; Reidsma et al., 2020). This implied that some attributes specifically emphasized by other authors like Tittonell (2020), including "ecologically self-regulated", "reflective and shared learning", and "builds human capital", were omitted. While these attributes do overlap with others, Figure 2 also showed that stakeholders do have attention for strategies related to these attributes. 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 (see also Soriano et al., 2020).

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). 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. On the other hand, a strong focus on agro-ecological transition of farming systems (e.g. Tittonell, 2020), may result in an overemphasis on diversity and redundancy, neglecting the importance of (short-term) economic viability. Farming systems are embedded in socio-technological regimes, and sustainability and resilience of farming systems also depend on the context, as also shown in the scenario compatibility analysis (section 3.5). 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. A key question is thus how institutions should govern investment in and the use of resources and capacities (Mathijs and Wauters, 2020).

4.3 Participatory assessment

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 for bottom-up innovation and change (Mosse, 1994; Timilsina et al., 2020). 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, Further, different types of stakeholders were consulted in each case study, and the synthesis 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. LastlyIn additionFurthermore, part of the work was executed by case study researchers, to ensure good understanding of the concepts. Lastly, different types of stakeholders were consulted in each case study, and the synthesis of results across case studies averaged out opinions of individuals or case study specific results.

In addition,

in the SURE-Farm project we applied a range of qualitative and quantitative approaches to improve understanding of sustainability and resilience in 11 European farming systems (Reidsma et al., 2019; Accatino et al., 2020; Meuwissen et al., 2021).

Whereas the current assessment was mainly based on FoPIA-SURE-Farm I and II to ensure consistency, these methods were complemented with other methods and triangulation took place to assess consistency of results. For example, we useding system dynamics modelling, where we combined stakeholders' perspectives with theories and empirical evidence, to found in the literature and checked the coherency of perspectives by looking at them from a system perspective (Herrera et al., 2022; Reidsma et al., 2020b). We also used statistical modelling to assess specific functions and resilience capacities of EU farming systems (Slijper et al., 2020; Paas et al., 2023). This mixed-methods approach allows a comprehensive insight in current and future sustainability and resilience of EU farming systems (Meuwissen et al., 2022; Meuwissen et al., 2021). iFurther, different types of stakeholders were consulted in each case study, and the synthesis 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 was executed by case study researchers, to ensure good understanding of the concepts.~~

With the objective to ~~identify alternative systems to~~ improve sustainability and resilience of EU farming systems, the alternative systems identified in this study should not be seen as the final, but as the starting point. Alongside this bottom-up assessment, top-down assessments were performed with 'critical friends' (participants invited as experts, not as representatives of specific interests) to identify policy recommendations for more resilient farming systems (Buitenhuis et al., 2020a). 'Critical friends' are less bounded to the current situation, and their tendency towards more transformative strategies can complement the more operational focus of the local stakeholders in this study. Also more radical top-down visions of future food and farming systems (Bodirsky et al., 2022; van Zanten et al., 2023) can complement the actor-supported visions, but a participatory process is needed to make a change. ~~Later,~~ The results of the current study and other ~~of all~~ approaches were used to discuss archetypical patterns identified in the various case studies and on how actions in the enabling environment tend to constrain the resilience of farming systems (Mathijs et al., 2022). Based on this, principles and recommendations for an enabling environment that fosters resilience, including transformation, were formulated. Resilience policy dialogues need to continue in the case studies, gathering all relevant actors from the farming system and its environment, based on a shared goal, information and data, a formalised and agreed time frame, and a monitoring and evaluation framework (Mathijs et al., 2022). These dialogues should be accompanied by one-to-one discussions, which are less bounded by social pressure, where ‘miracle questions’ (‘imagine that a miracle happens that results in a transformed and ideal agriculture’) can allow to think further out-of-the-box (Moore and Milkoreit, 2020; Young et al., 2023). This should pave the way towards alternative systems, which may become more transformative over time.

5 Conclusion

In this study, stakeholders identified alternative systems, aimed at improving main system functions and resilience attributes. Most alternatives suggested that stakeholders were preferring ~~incremental~~ adaptations, rather than radical transformations of current systems. Incremental change may however lead to transformations in the longer-term, and the identification of alternative systems should be seen as a starting point for a transition process. In most case studies, desired alternative systems emphasizing technology, diversification and organic and/or nature friendly farming were identified. In some case studies, also systems emphasizing intensification, specialization, improved product valorization, collaboration, and an attractive countryside were ~~attractive~~ options that can increase sustainability and resilience.

The resilience of current farming systems is low, as strategies have been mainly focused on strengthening the economic sustainability dimension and robustness resilience capacity. To make a transition to alternative systems and improved resilience, strategies need to simultaneously reinforce economic (less focused on scale enlargement and intensification, but more on developing new business models), environmental (e.g., soil quality, varieties adapted to local climatic conditions, reducing inputs, improving circularity), institutional (e.g., regulations, rewarding the delivery of public goods) and social (e.g., improving the level of connections of farming system actors with actors outside their system) sustainability dimensions. Maintaining profitability remains important, but it should not get the strong focus as it currently gets in most farming systems.

Different alternative systems will thrive under different enabling environments, and therefore all may be feasible options, but this depends on future scenarios. Most alternatives mainly thrive in the scenario ‘agriculture on sustainable paths’, while being specifically vulnerable in ‘agriculture on separated paths’. Flexibility is required for farming system actors to adjust the strategies according to the nature of future conditions. Simultaneously, for thriving European farming systems, EU policies should be directed at “unfolding” the “agriculture on sustainable paths” scenario while stimulating macro-level institutional, social, economic and technological developments that seem lacking in this specific scenario. Farmers need to be supported by other actors in the farming systems and the enabling environment, in order to realize more sustainable and resilient European farming systems.

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Appendix B

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Declaration of interests

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