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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

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

3 **Highlights**

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

14

15

16 Graphical abstract

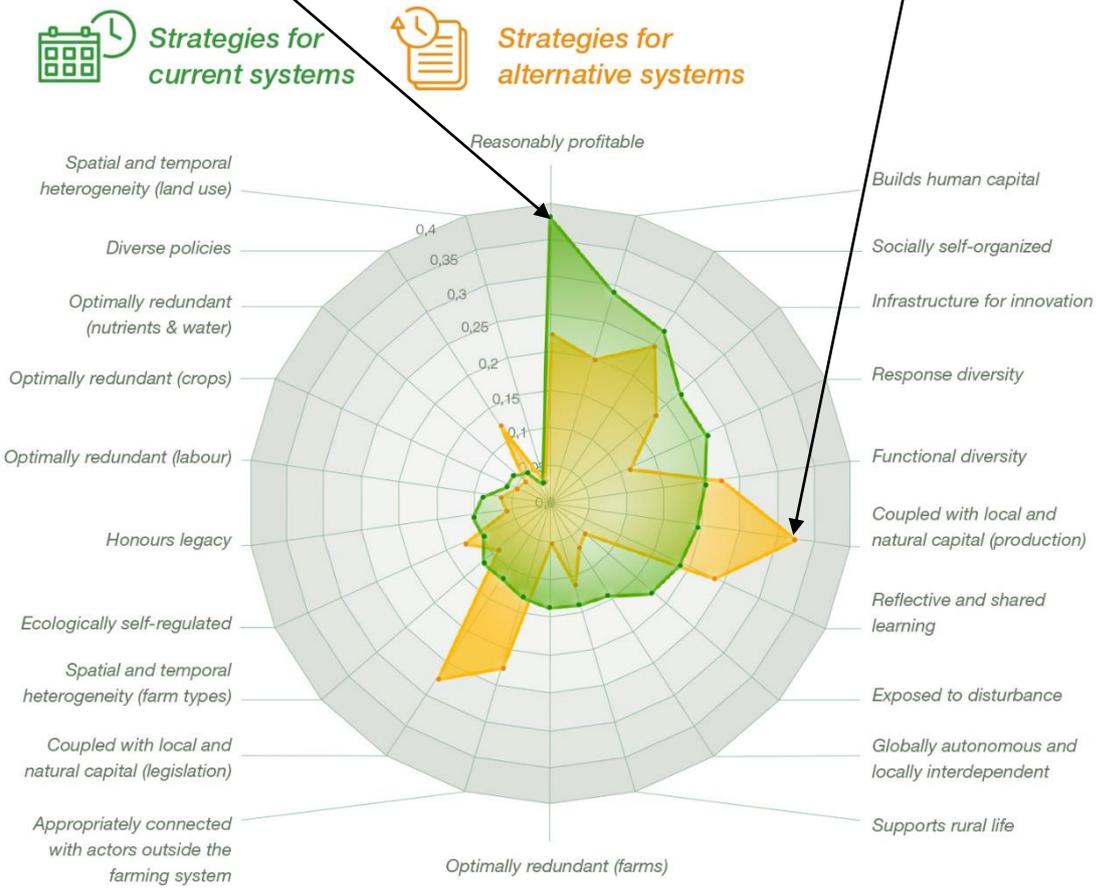
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Past strategies to improve resilience were often geared towards remaining 'reasonably profitable'

Future strategies to improve resilience need to couple production and legislation to local and natural capital, strengthen functional diversity, connect actors and stimulate learning



20

21

22 **Abstract**

23 According to stakeholders, many European farming systems are close to critical thresholds
24 regarding the challenges they face (e.g., droughts, price declines), functions they deliver (e.g.,
25 economic viability, biodiversity and habitat) and attributes required for resilience (e.g., social
26 self-organization). To accelerate a transition process towards sustainable and resilient
27 agriculture, this study aimed to identify actor-supported alternative systems across 10
28 European farming systems, and to identify associated future strategies that contribute to
29 strengthening resilience attributes, using a backcasting approach. This paper synthesizes 1) the
30 participatory identification of desired alternative systems and their expected performance on
31 sustainability and resilience, 2) the participatory identification of strategies to realize those
32 alternative systems, 3) the contribution of identified past and future strategies to 22 resilience
33 attributes, and 4) the compatibility of the status quo and alternative systems with different
34 future scenarios, the Eur-Agri-SSPs. Many identified alternative systems emphasized
35 technology, diversification and organic and/or nature friendly farming, while in some farming
36 systems also intensification, specialization, better product valorization, collaboration, and
37 creating an attractive countryside could increase sustainability and resilience. Low economic
38 viability limited farming system actors to pay attention to environmental and social functions.
39 Further, most alternative systems were adaptations rather than transformations. Many
40 stakeholders had difficulty to envisage systems without the main products (e.g., starch potato
41 in NL-Arable, sheep in ES-Sheep and hazelnut in IT-Hazelnut), but in few cases transformative
42 systems were designed (e.g. local organic farming in PL-Horticulture and RO-Mixed).
43 Sustainability and resilience can be enhanced when alternative systems and strategies are
44 combined, thereby improving multiple functions and attributes at once. In particular,
45 production and legislation need to be coupled to local and natural capital. Identified alternative
46 systems seem only compatible with Eur-Agri-SSP1 'agriculture on sustainable paths'. This
47 requires policies at EU-level that stimulate macro-level social, institutional, economic, and

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

54 **Keywords:** resilience, sustainable development, backcasting, stakeholders, participatory,
55 scenarios

56 1 Introduction

57 Farming systems in Europe are increasingly challenged by economic, environmental, social, and
58 institutional changes (Meuwissen et al., 2020). Prices have become more volatile with
59 liberalization of markets, and climate change has led to higher temperatures and more
60 extremes including very dry summers in recent years, resulting in yield reductions. In addition,
61 policies are constantly changing, with generally more attention for environmental issues such
62 as greenhouse gas mitigation, biodiversity, and nitrogen emissions, but not all farmers can keep
63 up with the speed of change (Gomes and Reidsma, 2021; Spiegel et al., 2019). In the meantime,
64 farm sizes are increasing and the number of farmers decreasing, resulting in less attractive rural
65 areas (Mandryk et al., 2012; Pitson et al., 2020). Recently, the COVID-19 pandemic and the
66 resulting lock-downs caused specific shocks, notably for systems relying on catering, export and
67 agritourism (Meuwissen et al., 2021; Savary et al., 2020). All these shocks and stresses affect
68 the sustainability and resilience of European farming systems.

69 In 2019, the European Commission proposed The European Green Deal, which was further
70 specified in the Farm-to-Fork and Biodiversity strategies (European Commission, 2019, 2020a,
71 b, c), promoting the transition to sustainable and inclusive agricultural production. The

72 European Green Deal is a comprehensive policy approach promoting transformation of the EU
73 food system to be environmentally friendly, socially responsible, able to preserve ecosystems
74 and biodiversity, and to contribute to a climate-neutral European economy. It takes a holistic
75 approach by targeting the whole EU food system from farmers to consumers by covering food
76 production, transport, distribution, marketing, and consumption as well as global trade and
77 global food sustainability standards. General action points for initiating transformation are
78 listed, but more knowledge is needed to identify which specific (and local) actions lead to more
79 sustainable and resilient agricultural systems. In addition, knowledge is needed on which
80 actions correspond with the wishes, capacities and willingness of farming system actors, as they
81 are key in initiating actions on the ground.

82 In the SURE-Farm project, we developed a framework to assess the resilience of farming
83 systems (Meuwissen et al., 2019), which can be used for the purpose of identifying
84 sustainability and resilience enhancing strategies. Resilience of a farming system can be defined
85 as its ability to ensure the provision of the system functions in the face of increasingly complex
86 and accumulating economic, social, environmental and institutional shocks and stresses,
87 through capacities of robustness, adaptability and transformability (Meuwissen et al. 2019).
88 Sustainability is a concept complementary to resilience and refers to the adequate
89 performance of all system functions across the environmental, economic and social domains
90 (Morris et al. 2011). The framework includes five main steps: 1) identifying the resilience of
91 what? (farming system), 2) to what? (challenges), and 3) for what purpose? (functions and their
92 sustainable performance level); 4) assessing the resilience capacities of robustness, adaptability
93 and transformability; and 5) assessing resilience attributes that contribute to the general
94 resilience of a farming system, i.e. the system's capacity to appropriately respond to any kind
95 of stress or shock.

96 Three resilience capacities can be distinguished, as a system can respond to challenges in
97 different ways: by coping with shocks and stresses (robustness), by actively responding to
98 shocks and stresses without changing the system structure (adaptability), or by reorganizing its
99 structure (transformability) (Folke et al., 2010; Ge et al., 2016; Meuwissen et al., 2019).

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

110 Based on the framework by Meuwissen et al. (2019) a range of quantitative and qualitative
111 methods was employed to investigate sustainability and resilience in 11 European farming
112 systems (Meuwissen et al., 2022; Meuwissen et al., 2021). Impact assessments often use
113 quantitative models (e.g. Helming et al., 2011; Herrera et al., 2018; Reidsma et al., 2015; Van
114 Ittersum et al., 2008). Quantitative models are useful to analyse current systems based on
115 statistical data (Dardonville et al., 2021; Reidsma et al., 2010; Slijper et al., 2020), and to
116 simulate the impact of specific scenarios on specific indicators (e.g., Herrera et al., 2022), but
117 resilience of farming systems is too complex to be captured by single models (Accatino et al.,
118 2020). For some indicators, accurate data and process knowledge are available, while for others
119 data are lacking, and therefore such indicators are often ignored (e.g. the attractiveness of a
120 rural area for residents and visitors is difficult to capture with quantitative indicators). In

121 addition, to assess resilience, dynamics of multiple processes need to be investigated
122 simultaneously (Kinzig et al., 2006; Walker and Salt, 2012). It has earlier been argued that it is
123 nearly impossible to account for every factor that contributes to resilience both now and in the
124 future, and that using surrogate indicators is more useful than trying to measure resilience itself
125 (e.g. Cabell and Oelofse, 2012; Darnhofer et al., 2010). Qualitative approaches are needed to
126 understand the dynamics of farms and to address the above-mentioned issues (Darnhofer,
127 2014). Participatory assessments allow to consistently follow all steps required in order to
128 provide a holistic picture (Ashkenazy et al., 2018; Payne et al., 2019; Sellberg et al., 2017;
129 Walker et al., 2002). In addition, in order to follow-up on an assessment and allow for a
130 transition process, farming system actors (stakeholders and the enabling environment; see
131 Meuwissen et al., 2019) need to be part of the assessment (Quist and Vergragt, 2006). Hence,
132 we first assessed sustainability and resilience of *current* European farming systems with a
133 structured participatory method (Paas et al., 2020; Reidsma et al., 2020a), and next, we
134 addressed sustainability and resilience of *future* farming systems in collaboration with relevant
135 actors (Paas et al., 2021a; Paas et al., 2021b).

136 According to stakeholders in the first round of workshops in the selected European farming
137 systems, sustainability and resilience of current systems is low (Paas et al., 2020; Reidsma et
138 al., 2020a). In the first part of the second round of workshops, on future systems, it was
139 concluded that many of the current systems are close to critical thresholds regarding the
140 challenges they face (e.g., droughts, price declines), functions they deliver (e.g., economic
141 viability, biodiversity and habitat) and attributes required for resilience (e.g., social self-
142 organization) (Paas et al., 2021a). A quantitative modelling study confirmed closeness to critical
143 thresholds for the Dutch case study, and showed that only actively implementing strategies
144 allowed the system to remain resilient (Herrera et al., 2022). However, across Europe strategies

145 have, so far, mainly focussed on robustness, and lack attention for adaptability and
146 transformability (Buitenhuis et al., 2020b; Paas et al., 2020; Reidsma et al., 2020a).

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

154 **2 Material and methods**

155 **2.1 Participatory assessment of resilience and sustainability of farming systems**

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

159

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	Government	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			

160

161

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

171 FoPIA-SURE-Farm I (Nera et al., 2020; Paas et al., 2020; Reidsma et al., 2020a), was conducted
172 in the 10 case studies presented in Table 1 and a case study on dairy farming in Flanders,
173 Belgium. In each case study, one workshop of around six hours was held between November
174 2018 and March 2019. The number of participants differed between 6 and 26, and represented
175 farmers, industry, NGOs, government, research and advice, and others, with a total of 184
176 participants (Paas et al., 2020). In brief, the workshops focused on: 1) ranking the importance
177 of functions (private and public goods) and selecting representative indicators for these
178 functions; 2) scoring the current performance of the representative indicators; 3) sketching
179 past dynamics of main representative indicators of functions; 4) identifying which challenges
180 caused these dynamics and which strategies were implemented to cope with these challenges;
181 5) assessing level of implementation of identified strategies and their potential contribution to
182 the robustness, adaptability and transformability of the farming system; and 6) assessing the
183 level of resilience attributes and their potential contribution to the robustness, adaptability and
184 transformability of the farming system.

185 In FoPIA-SURE-Farm II (Paas et al., 2021b), a workshop of around four hours was held between
186 November 2019 and March 2020 in 9 case studies, and in 1 case study (FR-Beef) a desk study

187 was performed, as the COVID-19 crisis prevented the realization of the workshop. In the desk
188 study, inputs from stakeholders and experts, based on earlier work and literature, were
189 considered. Only specific results from this case study are included. A desk study was also
190 performed in the aforementioned Belgian case study, but this case is excluded from the current
191 paper as it focused on the status quo only. The number of participants ranged between 5 and
192 22, with a total of 128 participants (Table 1; Paas et al., 2021a). The first half of the workshop
193 was focused on forecasting in relation to maintaining the status quo and system decline in case
194 critical thresholds would be exceeded, and results for the 10 European farming systems and
195 the one in Belgium are described in Paas et al. (2021a). This forecasting approach included an
196 assessment of: 1) the development of current systems; 2) identification of critical thresholds
197 whose exceedance can lead to large and permanent system change; 3) an assessment of the
198 developments when critical thresholds are exceeded. These steps build on FoPIA-SURE-Farm I,
199 as the previously identified most important functions, challenges and resilience attributes were
200 considered for this assessment.

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

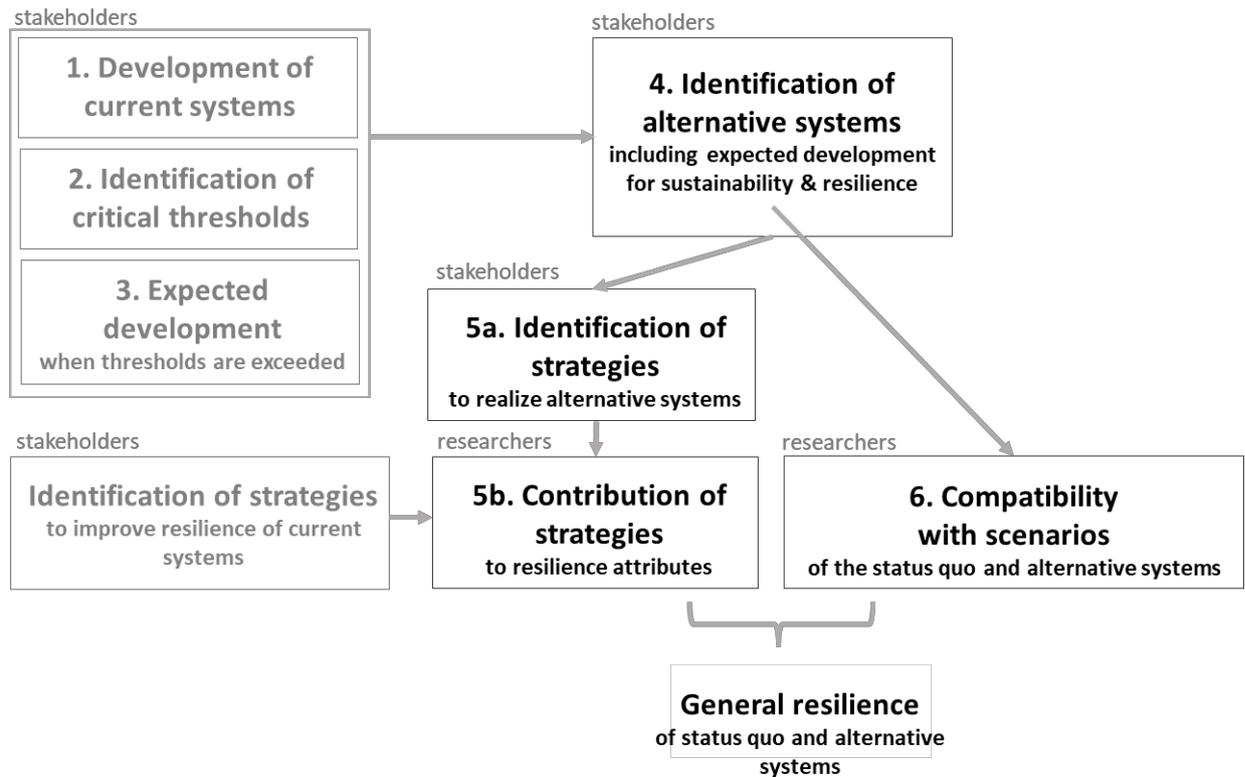
212 Methods and results of all six steps of FoPIA-SURE-Farm II are described in detail for extensive
213 sheep farming in Huesca, Spain, in Paas et al. (2021b). Paas et al. (2021b) present results from
214 the first part across European farming systems, providing forecasts for current systems. In this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

222 **2.2 Backcasting to design and evaluate alternative systems and strategies**

223 Starting with step 4 of FoPIA-SURE-Farm II, we present the identification of alternative systems
224 for the future (Figure 1). All participants in the workshops were asked individually to envisage
225 one or more alternative systems they desired towards 2030 if challenges, functions and/or
226 resilience attributes would cross critical thresholds. Stakeholders were asked for desired
227 transformations, but adaptations were also accepted. Next, in a plenary session in each case
228 study workshop an inventory was made on common alternative systems. Suggestions by
229 individuals were grouped into 2-4 alternative systems. These were considered to be potential
230 future systems, along with maintaining status quo, and system decline (when essential
231 requirements are not met), which serve as a reference.

232 For the cross-case study comparison, alternative systems were categorized according to the
233 most important direction that an alternative system is taking (e.g., specialization), according to
234 the interpretation of the research team in each case study. Categories are hence not mutually
235 exclusive and alternative systems can have elements of multiple categories. The categories that

236 came forward in this study are also not exhaustive in the sense that they do not cover all
 237 directions that alternative systems can take.



238

239 Figure 1. Steps in the backcasting approach of FoPIA-SURE-Farm II to identify alternative systems that contribute
 240 to sustainability and resilience, and to identify associated strategies and developments in future scenarios that
 241 contribute to general resilience. Step 4-6 (in black) refer to backcasting and are addressed in this paper. Step 1-3
 242 (in grey) refer to the forecasting part of FoPIA-SURE-Farm II, which serves as input for the assessment, together
 243 with 'Identification of strategies to improve resilience of current systems' coming from FoPIA-SURE-Farm I. Step
 244 1-5a are stakeholder-based, and step 5b and 6 are researcher-based.

245 Subsequently, stakeholders were divided in small groups and within each group one alternative
 246 system was discussed (or in subsequent sessions when the number of participants was too
 247 small) with regard to main function indicators, resilience attributes and enabling conditions. A
 248 selected set (based on FoPIA-SURE-Farm I) of main function indicators and resilience attributes
 249 was discussed per case study (see Table SM1.5 of Paas et al., 2021b) as critical system changes
 250 are expected to be determined by a small set of key variables (Kinzig et al., 2006).
 251 Developments were classified as strongly negative (-2), moderately negative (-1), no impact (0),

252 moderately positive (+1) and strongly positive developments (+2). For the synthesis across case
253 studies, the minimum and maximum of expected developments per function (eight in total)
254 and resilience attribute (13 in total) were evaluated and translated into arrows with the same
255 meaning. These were compared with the average expected developments for the status quo
256 and system decline (Paas et al., 2021a).

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

264 A farming system can be resilient to specific challenges (specified resilience), and strategies can
265 be implemented to deal with such challenges, but this does not necessarily imply that the
266 farming system is capable to deal with the unknown, uncertainty and surprise (general
267 resilience). General resilience can be judged based on the presence of resilience attributes
268 (Meuwissen et al., 2019; Cabell and Oelofse, 2012). An additional step 5b was therefore
269 included to assess the impact of strategies on general resilience. After the workshops,
270 researchers assessed the contribution (either yes or no) of the identified past and future
271 strategies to 22 resilience attributes (see Appendix B for full description). In the assessments
272 with stakeholders, 13 out of these 22 were selected to be discussed, but researchers were
273 assumed to be able to address all 22, allowing to assess which ones from the full list were most
274 important (also in comparison to the selected 13). Similar to Soriano et al. (2020), resilience
275 attributes were inferred based on statements regarding strategies, using the definition,
276 implication and characteristics of the attributes (Appendix B). The 22 attributes are associated

277 to the 5 general resilience principles (system reserves, tightness of feedbacks, diversity,
278 modularity and openness; Appendix B; Meuwissen et al., 2019). The first and last author of this
279 paper did a first assessment across all case studies, this was checked per case study by case
280 study partners, and evaluated again by the first and last author. Results were synthesized based
281 on the relative share of strategies contributing to a resilience attribute, where the contribution
282 of future strategies to reach alternative systems was compared with (past) strategies
283 implemented for current systems.

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

295 In step 6 of FoPIA-SURE-Farm II, the compatibility of the future farming systems (status quo and
296 alternative systems) with the directions of change of the storyline elements as projected in
297 these five Eur-Agri-SSPs was assessed. For each future farming system, case study partners
298 indicated how important an increase in the scenario elements (related to the sections
299 Population, Economy, Policies & institutions, Technology and Environment & Natural
300 resources) as proposed by Mitter et al. (2020) was, where 0 is not important, 1 is somewhat
301 important and 2 is very important. Expected developments of scenario elements were based

302 on Mitter et al. (2020), with -1, 0 and 1 indicating negative, no and positive changes,
303 respectively. Multiplication of the importance of developments for future systems with
304 expected developments of scenario elements was used as an approximation for compatibility.
305 Final compatibility scores per future system per scenario was an average of the overall section
306 scores, where values -1 to -0.66 imply strong incompatibility, -0.66 to -0.33 moderate
307 incompatibility, -0.33 to 0 weak incompatibility, 0 to 0.33 weak compatibility, 0.33 to 0.66
308 moderate compatibility, and 0.66 to 1 strong compatibility. An example for ES-Sheep is
309 presented in Paas et al (2021c). For the comparison across case studies, compatibility scores
310 per Eur-Agri-SSP were averaged per category of the alternative systems.

311

312 **3 Results**

313 **3.1 Alternative farming systems**

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

323 The alternative systems could broadly be grouped in eight categories with three main
324 directions: 1) intensification / specialization / technology / product valorization with a focus on
325 improving production and economic functions and attributes; 2) collaboration / attractive

326 countryside, with a focus on improving social functions and attributes; and 3) diversification /
327 organic / nature friendly with a focus on improving environmental functions and attributes. In
328 relatively more extensive systems like DE-Arable&Mixed, RO-Mixed, ES-Sheep, FR-Beef and PL-
329 Horticulture, alternative systems focused on intensification or specialization were seen as
330 relevant and viable options. Also in SE-Poultry, further intensification was considered as an
331 option. Many case studies considered alternatives which focused on technology development,
332 where generally new technologies should also allow for improving the maintenance of natural
333 resources and biodiversity (e.g. precision agriculture in NL-Arable, high-tech extensive
334 production in ES-Sheep, robots in SE-Poultry). In several case studies, alternatives focusing on
335 collaboration among actors in- and outside of the farming system were specifically identified,
336 emphasizing the need for social interaction in order to improve other functions, such as food
337 production and maintaining natural resources. Lastly, all case studies identified alternatives in
338 relation to diversification and nature friendly agriculture, focusing on improving environmental
339 functions and attributes (however, for ES-Sheep grouped under technology). In many case
340 studies they were seen as ambitious and subject to many enabling conditions.

341 Clearly, the categories are not mutually exclusive, e.g. organic / nature friendly could be
342 combined with a change towards diversification (NL-Arable) or specialization (PL-Horticulture).
343 In most case studies, alternative systems were perceived as compatible with one another at
344 the same time at farm and/or farming system level (BG-Arable, DE-Arable&Mixed, NL-Arable,
345 SE-Poultry, IT-Hazelnut, ES-Sheep), and/or over time at the farming system level (e.g., the likely
346 system may evolve into the desired system in UK-Arable).

347

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

Category	Case studies										Total ¹ (n)
	BG-Arable	NL-Arable	UK-Arable	DE-Arable&Mixed	RO-Mixed	ES-Sheep	FR-Beef	SE-Poultry	PL-Horticulture	IT-Hazelnut	
Intensification				Intensification		Semi-intensive		Large farms			3
Specialization					Commercial specialization of family mixed farms		Only-for-export production		Horticulture farming		3
Technology	Innovation and technology	Precision agriculture				Hi-tech extensive		Robots	Shelter farming	Technological innovation	6
Product valorization	Processing and increasing added value						Production only for the French market			Product valorization	3
Collaboration	Collaboration	Collaboration & water			Cooperation / multifunctionality						3
Attractive countryside				Better societal appreciation			Development of tourism			Sustained demand (high and stable prices)	3
Diversification	Crop diversification	Alternative crops	Likely system		Alternative crops / livestock			Self-sufficiency fodder			5
Organic / nature friendly		Nature-inclusive	Desirable system	Organic farming	Organic agriculture				Local organic farming	Eco-friendly agriculture	6
Total (n)	4²	4	2	3	4	2	3	3	3	4	32

349 ¹For FR-Beef, a desk study with researchers was conducted instead of a workshop with stakeholders.

350 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.

351 3.2 Development of future systems

352 Future systems include maintenance of the *status quo*, system decline when critical thresholds
353 are exceeded and the desired alternative systems. We use the function and attribute
354 development under continued status quo and system decline, which are described in Paas et
355 al. (2021b), as points of reference. A summary is provided in the remainder of this paragraph.
356 When maintaining status quo under the current challenges, on average indicators representing
357 “economic viability” and “attractiveness of the area” were expected to decrease. In the one
358 case study where “quality of life” was discussed (DE-Arable&Mixed), the provision of this
359 function was also expected to largely decrease. On average, for the continued status quo, no
360 large negative changes were expected for resilience attributes, except for “reasonably
361 profitable” and “appropriately connected with actors outside of the system”. When critical
362 thresholds would be exceeded, and system decline would take place, almost all functions and
363 attributes were expected to be negatively affected.

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

370 Minimum and maximum developments of farming system functions in alternative systems
371 indicate that for most functions at best moderate improvements are expected (Table 3;
372 Appendix C). For “food production”, “natural resources” and “biodiversity & habitat”, minimum
373 developments were expected to be stable, suggesting that these functions cannot be improved
374 in all alternative systems. For “quality of life” (evaluated once) and “biodiversity & habitat”
375 (evaluated four times), the average maximum development is expected to be strongly positive,
376 while the average minimum development is expected to be negative and stable, respectively.
377 This indicates that for these functions, alternative systems seem to take different directions,
378 and stakeholders foresee trade-offs.

379 Under alternative systems, “food production” is perceived to at least not change and at most
380 moderately improve. For “economic viability” negative developments under status quo are
381 expected to at least be countered by alternative systems and at most be turned into moderate
382 positive developments. For “natural resources”, expected stability under status quo across case
383 studies is expected to become at least slightly improved and at most moderately improved by
384 alternative systems. In UK-Arable, negative developments for indicators representing “quality
385 of life” and “biodiversity & habitat” were expected to continue in the “likely” alternative
386 system. In multiple case studies, some alternative systems resulted in negative developments
387 for “food production” (BG-Arable), “bio-based resources” (DE-Arable&Mixed, RO-Mixed),
388 “economic viability” (BG-Arable and SE-Poultry) and “natural resources” (SE-Poultry, NL-
389 Arable), implying a trade-off as overall performance of main indicators was expected to
390 improve.

391 Table 3. Developments of system indicators per function and resilience attributes for the status quo, system
 392 decline and minimum and maximum developments in alternative systems. Arrows down (↓) and brown imply
 393 strong negative, down-right (↘) and orange moderate negative, straight (→) stable, right-up (↗) and light green
 394 moderate positive, and up (↑) and dark green strong positive developments, with others in-between.

Function/resilience attribute	Name	Number of times discussed	Expected average developments in future systems			
			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	→	↘	→↘	↗↑

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

396 Minimum and maximum developments were expected to be stronger for resilience attributes
 397 than for functions. This suggests that stakeholders have more trust in the ability to improve
 398 resilience attributes than in the effect this will have on improving the performance level of

399 system functions. In particular, “production coupled with local and natural capital” and
400 “infrastructure for innovation” were often evaluated and expected to show moderate to strong
401 positive developments in proposed alternative systems. The maximum was high, but also the
402 minimum was relatively high, suggesting that stakeholders considered these attributes as
403 prerequisites for alternative systems. Also “socially self-organized” and “appropriately
404 connected with actors outside of the system” showed large potential for improvement in
405 multiple alternative systems.

406 **3.3 Identification of past and future strategies**

407 Strategies that were mentioned by participants as being implemented in the past and
408 suggested for alternative systems (see Appendix D for a complete overview) had different
409 degrees of specificity: some strategies were umbrella strategies and overarched a set of more
410 specific challenges, while other strategies were very specific actions and linked to one domain.

411 Across case studies, 112 strategies were identified as being implemented in the past to enhance
412 resilience of current systems, and an additional 88 were identified to reach alternative systems.

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

418 While in the past, strategies to remain resilient focused on the economic domain, when
419 envisaging future strategies attention shifted to other domains. Strategies that had been
420 important in the past, such as increasing farm size and intensity, do not contribute to most
421 alternative systems. However, in many case studies, economic strategies such as diversification
422 of income sources (ES-Sheep, FR-Beef, RO-Mixed, UK-Arable) remained important in at least
423 one of the alternative systems. Economic strategies thus remained relevant, but the nature
424 changed. For example, in NL-Arable, for three out of four alternative systems economic
425 strategies were identified, but the nature of the strategies shifted from scaling up production
426 and cost reduction towards developing a new business model.

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

437 Strategies primarily aimed at the social domain were mentioned in all case studies, except for
438 SE-Poultry. In SE-Poultry, stakeholders argued that knowledge sources were available and that

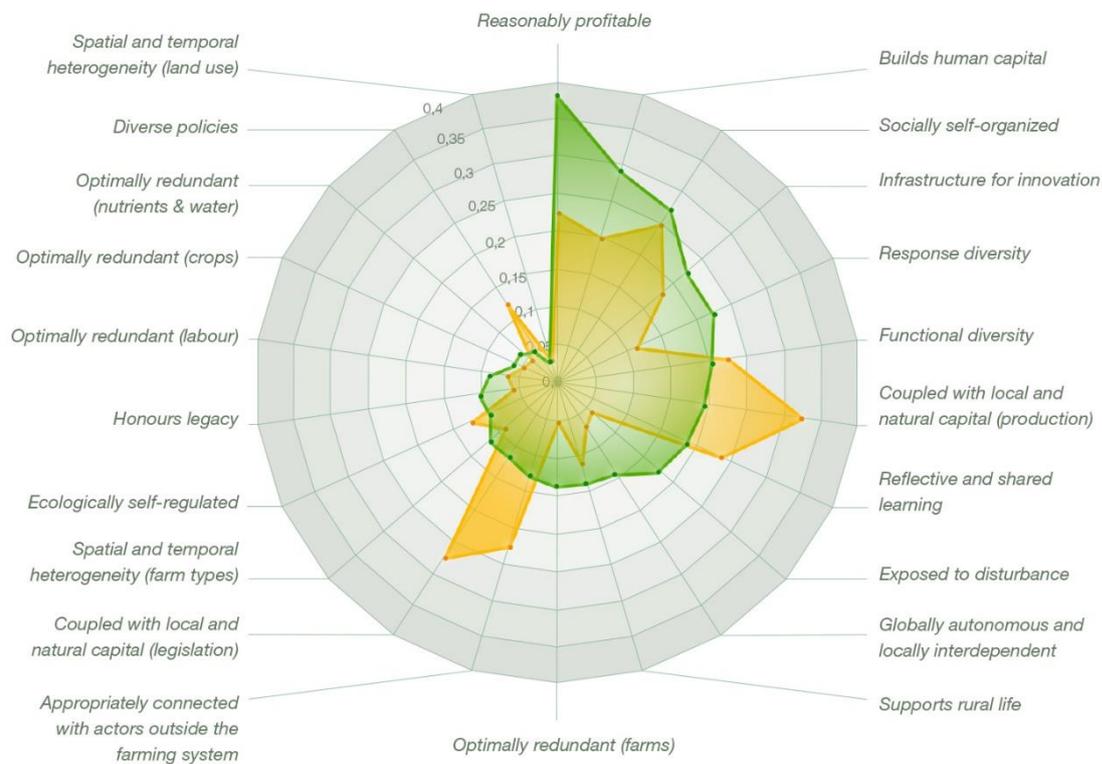
439 these were used to a good extent. Important strategies in the social domain included
440 cooperation and/or knowledge sharing among farming system actors (in a value chain and/or
441 cooperative) (all case studies having socially oriented strategies), and learning, education
442 and/or awareness raising strategies for actors inside the farming system (UK-Arable, NL-Arable,
443 IT-Hazelnut, BG-Arable, RO-Mixed) or aimed at producer-consumer connections (PL-
444 Horticulture, NL-Arable, ES-Sheep).

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

448 **3.4 How do past and future strategies impact resilience attributes?**

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

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



472

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

477 3.5 Compatibility of farming systems with future scenarios

478 Although different strategies are needed for different alternative systems, alternative systems
 479 generally thrive in the same scenario. Most future systems, including maintaining the status
 480 quo, are most compatible with Eur-Agri-SSP1 "Sustainable paths" (Table 4; Appendix E). This is
 481 mainly due to favourable developments regarding policies and institutions and technology,

482 which are environment-focused (e.g., agri-environmental payments increase), corresponding
483 with enabling conditions and strategies for most future systems (Appendix E). Also,
484 developments in the population may increase compatibility as citizen environmental awareness
485 is expected to increase and the rural-urban linkages to be strengthened. This is however not
486 important for all alternative systems. For instance, alternative systems that focus on
487 specialization in PL-Horticulture and RO-Mixed depend less on developments related to
488 population. For most arable systems, developments regarding the environment and natural
489 resources are also favourable and help to avoid further degradation beyond critical thresholds,
490 e.g. regarding soil quality. For arable systems, the need for improving soil quality also explains
491 lesser compatibility with other Eur-Agri-SSPs, where maintenance of natural resources is
492 expected to stay stable or even decline. It should be noted that too much attention for
493 environmental performance might threaten certain crops that under conventional cultivation
494 depend on crop protection products, e.g. potato. The most compatible development would be
495 towards alternative systems primarily driven by organic / nature friendly production under Eur-
496 Agri-SSP1, but also product valorization and intensification seem to be very compatible with
497 this scenario.

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

Category	future systems	Future systems [#]	Average compatibility score with Eur-Agri-SSPs				
			SSP1 "Sustainable"	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 Product valorization	6	0.61	0.30	-0.52	0.21	0.25	
Collaboration	2	0.68	0.26	-0.79	0.00	0.23	
Attractive countryside	3	0.63	0.26	-0.75	0.16	0.24	
Diversification	2	0.50	0.43	-0.62	0.26	0.52	
Organic / nature friendly	5	0.69	0.24	-0.50	0.07	0.14	
	6	0.71	0.36	-0.74	0.10	0.21	
Average¹		0.62	0.32	-0.60	0.15	0.26	

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

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

511 compatible, while also the systems emphasizing an attractive countryside (specifically in IT-
512 Hazelnut) are moderately compatible.

513 In Eur-Agri-SSP3 “Separated paths”, most rural-urban linkages, infrastructure, export, trade
514 agreements, institutions, technology levels and maintenance of natural resources are expected
515 to decline, which is only expected to be compensated by increased commodity prices and direct
516 payments. Eur-Agri-SSP3 seems, therefore, most incompatible with most future systems in all
517 case studies, especially because many farming systems currently produce for international
518 markets and/or depend on technology and maintenance of remaining natural resources. SE-
519 Poultry is an exception to this, because of the current experienced mismatch between Swedish
520 national food production quality requirements and EU free trade agreements. SE-Poultry is
521 mainly producing for its own national market. Closing borders and decreased trade agreements
522 would consequently imply an increase in a competitive advantage over cheaper produced,
523 lower quality products from other countries (under the condition that technology and feed are
524 also locally produced). Loss of competitive advantage because of mismatches between
525 regulations was also mentioned by participants in DE-Arable&Mixed and PL-Horticulture, but
526 only to a limited extent.

527 Eur-Agri-SSP4 “Inequality paths” shows a mix of positive and negative developments. Storyline
528 elements in relation to population, such as rural-urban linkages are expected to decrease while
529 technology levels are expected to go up. Elements related to economy and policies and
530 institutions are showing both positive and negative developments. In Eur-Agri-SSP4, further
531 depletion of natural resources is expected, but probably at a slower rate due to increased

532 resource use efficiency. Altogether, future systems are weakly compatible with the
533 developments in Eur-Agri-SSP4. Alternative systems primarily driven by intensification,
534 specialization or technology seem to be most compatible with this SSP.

535 Alternative systems seem only weakly compatible with Eur-Agri-SSP5 “High-tech paths”. In Eur-
536 Agri-SSP5, technology levels will generally increase, but not necessarily made available to
537 agriculture, which is partly why alternative systems primarily driven by technology are not the
538 most compatible alternatives.

539 **4 Discussion**

540 **4.1 Contribution of alternative systems and associated strategies to sustainability and** 541 **resilience**

542 The main aim of this study was to identify sustainable and resilient alternative farming systems
543 and associated strategies for European farming systems. Results showed that when maintaining
544 status quo, specifically the functions “economic viability”, “attractiveness of the area” and
545 “quality of life” were judged to be at risk. Interacting thresholds regarding these functions may
546 lead to negative feedback loops (Paas et al., 2021a). Also resilience attributes “reasonably
547 profitable” and “appropriately connected with actors outside of the system” were expected to
548 develop negatively. Scientific literature often focuses on negative environmental impacts of
549 agricultural systems (e.g., Campbell et al., 2017; Springmann et al., 2018), and policies are
550 formulated to improve this, but deteriorating economic and social performance is of more
551 immediate concern for stakeholders from within the farming system. While social unrest (van

552 der Ploeg, 2020) suggests that farmers are not willing to change towards more sustainable
553 systems as demanded by society and policy, they are mainly concerned that additional requests
554 regarding environmental performance will render them economically unsustainable.

555 Desired alternative systems paid specific attention to the declining functions, but also to
556 improve “biodiversity and habitat”. While in some case studies it was argued that elements of
557 different alternative systems could be combined, in others they moved in different directions,
558 with opposite impacts on social and environmental functions. Stakeholder input provides good
559 starting points to understand which options provide most opportunities, but it should be noted
560 that identified alternative systems are rather adaptations than transformations.
561 Transformations require a change in norms and values (Rotmans, 2014), while stakeholders are
562 attached to and depend on the identity of a system, and specifically farmers largely focus on
563 short-term economic viability (Reidsma et al., 2020a). As long as economic viability is at risk, it
564 may however be argued that this is logical (Paas et al., 2021a). Stakeholders clearly have
565 attention for environmental and social functions, and larger transformations may gradually
566 evolve via a combination of incremental adaptation and ‘small wins’ (Termeer and Dewulf,
567 2019). Small wins are radical, but start at local level, and provide visible results and steps
568 forward towards a shared ambition. Stakeholders may not have trust in radical transformations,
569 but when they observe that strategies in the agronomic, economic, institutional and social
570 domain can be combined to make a change, this may also result in changed norms and values
571 and result in larger transformations in the longer term (De Kraker, 2017). New business models,

572 as mentioned by multiple stakeholders in our workshops, are needed to tackle long-term
573 challenges.

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

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

587 Strengthening the resilience attribute “infrastructure for innovation” was important in the past
588 and remains so for future systems. This resilience attribute is perceived by stakeholders to be
589 particularly important for transformability (Paas et al., 2020; Reidsma et al., 2020a).
590 Governments need to contribute to transformability by developing long-term visions and
591 continuous and improved legislation, and also their role and of other actors in the enabling

592 environment in investments and risk-management is crucial (Mazzucato, 2018). Translated to
593 resilience attributes, governments need to ensure “infrastructure for innovation” by
594 developing “diverse policies” (with less focus on robustness, and more on transformability),
595 and investing in risky strategies to make alternative directions “reasonably profitable”. The EU
596 Rural Development Programmes (RDP) provide good examples; in NL-Arable for example, these
597 subsidies stimulate innovation, and also allow to be “appropriately connected with actors
598 outside the farming system” (see [https://www.pop3subsidie.nl/blog/kennisbank/
599 veenkolonien-samenwerking-voor-innovaties/](https://www.pop3subsidie.nl/blog/kennisbank/veenkolonien-samenwerking-voor-innovaties/); in Dutch).

600 When assessing compatibility with future scenarios, some systems seem more resilient than
601 others. However, none of the systems can cope with all kinds of challenges. Especially in Eur-
602 Agri-SSP3, according to the scenario narrative, many resilience attributes are eroded. Enabling
603 conditions for maintaining status quo and reaching desired alternative systems are thus not
604 present in Eur-Agri-SSP3. Overall, we could, therefore, not identify “robust strategies” in the
605 sense that they aligned with all possible scenarios (see e.g. Kok et al., 2011; van Vliet and Kok,
606 2015). Instead, we argue that for European farming systems, EU policies should be directed at
607 avoiding certain scenarios, and stimulate the development towards a scenario that enables the
608 building of local and natural resources, the development of social self-organization and
609 technology that in turn will support the functions and resilience attributes previously
610 mentioned. Currently, the Eur-Agri-SSPs of Mitter et al. (2020) do not describe a scenario
611 containing all these elements, while alternative farming systems seem mostly compatible with
612 SSP1 “Sustainable paths”. This would imply that, when taking SSP1 as a point of departure,

613 which seems the case with the new Farm to Fork strategy, EU policies should specifically study
614 the possibilities to strengthen institutional, social, economic and technological developments
615 in this specific scenario. At local level, individual farming systems should be encouraged to
616 improve their compatibility with macro-level developments. As the compatibility scores are
617 averages of different macro-level developments (e.g. population, technology) of the narratives,
618 farming systems may be compatible with some, but not with other developments. A strategy
619 can thus focus on improving the compatibility with certain developments; even though at
620 European level such a development is not compatible, at local level actors can change this, at
621 least to some extent in their local context. The latter also refers again to the “small-wins”
622 approach (Termeer and Dewulf, 2019): small, meaningful steps with tangible results can be
623 energizing and lead to transformation at higher levels.

624 **4.2 Resilience attributes**

625 Resilience attributes considered were based on Cabell and Oelofse (2012), and adapted in the
626 context of the SURE-Farm project (Paas et al., 2019; Appendix B). “Infrastructure for
627 innovation” and “Support rural life” were added, and several attributes were split and adapted
628 to make them more specific for farming systems. The list of 22 attributes was however too long
629 to discuss with stakeholders, and therefore only the main 13 were assessed during the FoPIA-
630 SURE-Farm I workshops (Paas et al., 2021a; Nera et al., 2020; Reidsma et al., 2020). This implied
631 that some attributes specifically emphasized by other authors like Tittonell (2020), including
632 “ecologically self-regulated”, “reflective and shared learning”, and “builds human capital”, were
633 omitted. While these attributes do overlap with others, Figure 2 also showed that stakeholders

634 do have attention for strategies related to these attributes. On the other hand, Tiftonell (2020)
635 omitted “reasonably profitable” from his main list, while this attribute appeared to be the most
636 important according to our assessments (see also Soriano et al., 2020).

637 While the number of resilience attributes that need to be considered may be enlarged or
638 reduced, resilience attributes are suggested to be synergistic in nature, implying positive
639 interactions (e.g., Nemeč et al., 2014; Walker and Salt, 2012) or even purposely reinforcing
640 processes (Bennett et al., 2005). Under influence of the current institutional environment
641 and/or current socio-technological regime with a focus on production and economic functions,
642 synergistic effects seem to be diminished, which results in a one-sided approach to resilience.
643 On the other hand, a strong focus on agro-ecological transition of farming systems (e.g.
644 Tiftonell, 2020), may result in an overemphasis on diversity and redundancy, neglecting the
645 importance of (short-term) economic viability. Farming systems are embedded in socio-
646 technological regimes, and sustainability and resilience of farming systems also depend on the
647 context, as also shown in the scenario compatibility analysis (section 3.5). Synergistic effects
648 imply co-evolution. However, to realize resilience attributes, claims on the same resources
649 might be made. At the same time, resilience attributes may ensure the availability of resources
650 in the long term. A key question is thus how institutions should govern investment in and the
651 use of resources and capacities (Mathijs and Wauters, 2020).

652 4.3 Participatory assessment

653 Qualitative approaches to understand resilience are promoted (e.g. Darnhofer et al., 2010;
654 Cabell and Oelofse, 2012; Darnhofer, 2014; Walker et al. 2002; Ashkenazy et al. 2018; Payne et
655 al. 2018; Sellberg et al. 2017). However, participatory approaches have their caveats.
656 Participatory exercises are strongly influenced by existing social relationships, and information
657 is shaped by relations of power and gender, and by the investigators themselves (Mosse, 1994).
658 Therefore, it has been suggested that participatory assessments need to be complemented by
659 other methods of ‘participation’ which generate the changed awareness and new ways of
660 knowing, which are necessary for bottom-up innovation and change (Mosse, 1994; Timilsina et
661 al., 2020). Participatory approaches do not allow to understand individual thoughts, feelings,
662 or experiences (Hollander, 2004) and need to be complemented by interviews with individuals
663 to generate meaningful results. For this reason, the FoPIA-SURE-Farm approach itself did not
664 solely rely on group discussions, but also included individual assignments in order to collect
665 knowledge and perceptions of individuals. Furthermore, part of the work was executed by case
666 study researchers, to ensure good understanding of the concepts. Lastly, different types of
667 stakeholders were consulted in each case study, and the synthesis of results across case studies
668 averaged out opinions of individuals or case study specific results.

669 In addition, in the SURE-Farm project we applied a range of qualitative and quantitative
670 approaches to improve understanding of sustainability and resilience in 11 European farming
671 systems (Reidsma et al., 2019; Accatino et al., 2020; Meuwissen et al., 2021). Whereas the
672 current assessment was based on FoPIA-SURE-Farm I and II to ensure consistency, these

673 methods were complemented with other methods and triangulation took place to assess
674 consistency of results. For example, we used system dynamics modelling, where we combined
675 stakeholders' perspectives with theories and empirical evidence, to check the coherency of
676 perspectives (Herrera et al., 2022; Reidsma et al., 2020b). We also used statistical modelling
677 to assess specific functions and resilience capacities of EU farming systems (Slijper et al., 2020;
678 Paas et al., 2023). This mixed-methods approach allows a comprehensive insight in current and
679 future sustainability and resilience of EU farming systems (Meuwissen et al., 2022; Meuwissen
680 et al., 2021).

681 With the objective to improve sustainability and resilience of EU farming systems, the
682 alternative systems identified in this study should not be seen as the final, but as the starting
683 point. Alongside this bottom-up assessment, top-down assessments were performed with
684 'critical friends' (participants invited as experts, not as representatives of specific interests) to
685 identify policy recommendations for more resilient farming systems (Buitenhuis et al., 2020a).
686 'Critical friends' are less bounded to the current situation, and their tendency towards more
687 transformative strategies can complement the more operational focus of the local stakeholders
688 in this study. Also more radical top-down visions of future food and farming systems (Bodirsky
689 et al., 2022; van Zanten et al., 2023) can complement the actor-supported visions, but a
690 participatory process is needed to make a change. The results of the current study and other
691 approaches were used to discuss archetypical patterns identified in the various case studies
692 and on how actions in the enabling environment tend to constrain the resilience of farming
693 systems (Mathijs et al., 2022). Based on this, principles and recommendations for an enabling

694 environment that fosters resilience, including transformation, were formulated. Resilience
695 policy dialogues need to continue in the case studies, gathering all relevant actors from the
696 farming system and its environment, based on a shared goal, information and data, a
697 formalised and agreed time frame, and a monitoring and evaluation framework (Mathijs et al.,
698 2022). These dialogues should be accompanied by one-to-one discussions, which are less
699 bounded by social pressure, where ‘miracle questions’ (‘imagine that a miracle happens that
700 results in a transformed and ideal agriculture’) can allow to think further out-of-the-box (Moore
701 and Milkoreit, 2020; Young et al., 2023). This should pave the way towards alternative systems,
702 which may become more transformative over time.

703 **5 Conclusion**

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

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

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

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1 Alternative systems and strategies to improve future sustainability and resilience 2 of farming systems across Europe: from adaptation to transformation

3 Highlights

4 - Backcasting was used to identify alternative European farming systems supported by
5 stakeholders

6 - Low economic viability limited farming system actors to improve sustainability and
7 resilience

8 - To strengthen resilience, production and legislation need to be coupled to local and
9 natural capital

10 - Desired alternative systems are diverse but only compatible with the 'sustainable paths'
11 scenario

12 - To get stakeholders along, incremental adaptation rather than radical transformation
13 should be sought

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15

16 Graphical abstract

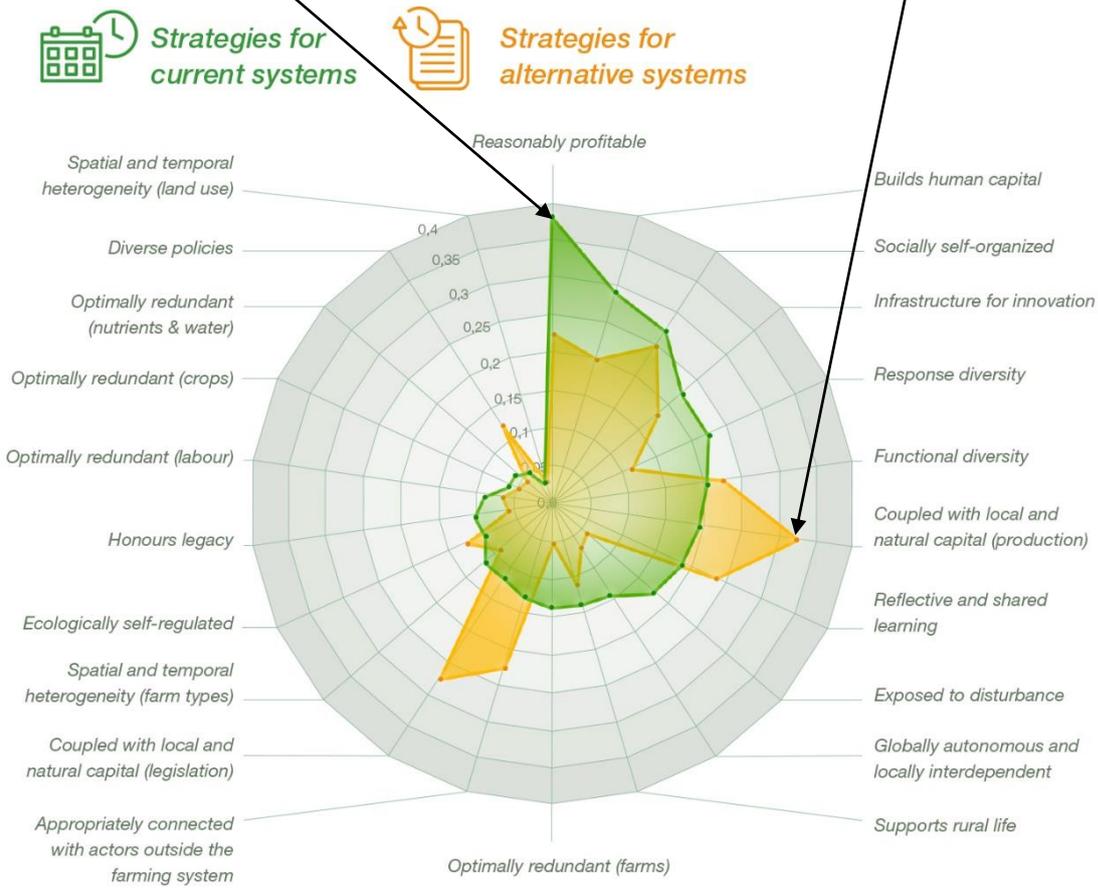
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Past strategies to improve resilience were often geared towards remaining 'reasonably profitable'

Future strategies to improve resilience need to couple production and legislation to local and natural capital, strengthen functional diversity, connect actors and stimulate learning



20

21

22 Abstract

23 According to stakeholders, many European farming systems are close to critical thresholds
24 regarding the challenges they face (e.g., droughts, price declines), functions they deliver (e.g.,
25 economic viability, biodiversity and habitat) and attributes required for resilience (e.g., social
26 self-organization). To accelerate a transition process towards sustainable and resilient
27 agriculture, this ~~paper study~~ aimeds to identify actor-supported alternative systems across 10
28 European farming systems, and to identify associated future strategies that contribute to
29 strengthening resilience attributes, using a backcasting approach. ~~†-This paper~~ synthesizes 1)
30 the participatory identification of desired alternative systems and their expected performance
31 on sustainability and resilience ~~-(stakeholder based assessment)~~, 2) the participatory
32 identification of strategies to realize those alternative systems ~~-(stakeholder based assessment)~~,
33 3) the contribution of identified past and future strategies to 22 resilience attributes
34 ~~(researcher based assessment)~~, and 4) the compatibility of the status quo and alternative
35 systems with different future scenarios, the Eur-Agri-SSPs ~~-(researcher based assessment)~~.
36 Many ~~desired~~ identified alternative systems emphasized technology, diversification and
37 organic and/or nature friendly farming, while ~~for in~~ some farming systems also intensification,
38 specialization, better product valorization, collaboration, and creating an attractive countryside
39 could increase sustainability and resilience. Low economic viability limited farming system
40 actors to pay attention to environmental and social functions. Further, most alternative
41 systems were adaptations rather than transformations. ~~As main products are part of the~~
42 ~~identity of the farming system,~~ Many stakeholders had difficulty to envisage systems without
43 the mainse products (e.g., starch potato in NL-Arable, sheep in ES-Sheep and hHh hazelnut in IT-
44 Hh hazelnut), but in few cases transformative systems were designed (e.g. local organic farming
45 in PL-Horticulture and RO-M mixed). Sustainability and resilience can be enhanced when
46 alternative systems and strategies are combined, thereby improving multiple functions and
47 attributes at once. In particular, production and legislation need to be coupled to local and

48 natural capital. ~~Desired-Identified~~ alternative systems seem only compatible with Eur-Agri-SSP1
49 ‘agriculture on sustainable paths’. This requires policies at EU-level that stimulate macro-level
50 social, institutional, economic, and technological developments that strengthen this scenario.

51 ~~We conclude that to get stakeholders along, incremental adaptation leading to transformation~~
52 ~~rather than radical transformation should be sought. The identification of envisaged alternative~~
53 ~~systems are is only a start for the transition process. Their analysis, along with the strategies~~
54 ~~identified, need to trigger the involvement of farmers and other ‘enabling actors’ inside and~~
55 ~~outside the farming systems, alongside farmers, to make a change, leading to~~
56 ~~transformation and where needed, systems can evolve into more transformative systems.~~

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

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

61 1 Introduction

62 Farming systems in Europe are increasingly challenged by economic, environmental, social, and
63 institutional changes (Meuwissen et al., 2020). Prices have become more volatile with
64 liberalization of markets, and climate change has led to higher temperatures and more
65 extremes including very dry summers in recent years, resulting in yield reductions. In addition,
66 policies are constantly changing, with generally more attention for environmental issues such
67 as greenhouse gas mitigation, biodiversity, and nitrogen emissions, but not all farmers can keep
68 up with the speed of change (Gomes and Reidsma, 2021; Spiegel et al., 2019). In the meantime,
69 farm sizes are increasing and the number of farmers decreasing, resulting in less attractive rural
70 areas (Mandryk et al., 2012; Pitson et al., 2020). Recently, the COVID-19 pandemic and the
71 resulting lock-downs caused specific shocks, notably for systems relying on catering, export and

72 agritourism (Meuwissen et al., 2021; Savary et al., 2020). All these shocks and stresses affect
73 the sustainability and resilience of European farming systems.

74 In 2019, the European Commission proposed The European Green Deal, which was further
75 specified in the Farm-to-Fork and Biodiversity strategies (European Commission, 2019, 2020a,
76 b, c), promoting the transition to sustainable and inclusive agricultural production. The
77 European Green Deal is a comprehensive policy approach promoting transformation of the EU
78 food system to be environmentally friendly, socially responsible, able to preserve ecosystems
79 and biodiversity, and to contribute to a climate-neutral European economy. It takes a holistic
80 approach by targeting the whole EU food system from farmers to consumers by covering food
81 production, transport, distribution, marketing, and consumption as well as global trade and
82 global food sustainability standards. General action points for initiating transformation are
83 listed, but more knowledge is needed to identify which specific (and local) actions lead to more
84 sustainable and resilient agricultural systems. In addition, knowledge is needed on which
85 actions correspond with the wishes, capacities and willingness of farming system actors, as they
86 are key in initiating actions on the ground.

87 In the SURE-Farm project, we developed a framework to assess the resilience of farming
88 systems (Meuwissen et al., 2019), which can be used for the purpose of identifying
89 sustainability and resilience enhancing strategies. Resilience of a farming system can be defined
90 as its ability to ensure the provision of the system functions in the face of increasingly complex
91 and accumulating economic, social, environmental and institutional shocks and stresses,
92 through capacities of robustness, adaptability and transformability (Meuwissen et al. 2019).
93 Sustainability is a concept complementary to resilience and refers to the adequate
94 performance of all system functions across the environmental, economic and social domains
95 (Morris et al. 2011). The framework includes five main steps: 1) identifying the resilience of
96 what? (farming system), 2) to what? (challenges), and 3) for what purpose? (functions and their

97 sustainable performance level); 4) assessing the resilience capacities of robustness, adaptability
98 and transformability; and 5) assessing resilience attributes that contribute to the general
99 resilience of a farming system, i.e. the system's capacity to appropriately respond to any kind
100 of stress or shock.

101 Three resilience capacities can be distinguished, as a system can respond to challenges in
102 different ways: by coping with shocks and stresses (robustness), by actively responding to
103 shocks and stresses without changing the system structure (adaptability), or by reorganizing its
104 structure (transformability) (Folke et al., 2010; Ge et al., 2016; Meuwissen et al., 2019).

105 Accordingly, adaptation is a change in the composition of inputs, production, marketing and
106 risk management but without changing the structures and feedback mechanisms of the farming
107 system, while transformation is a change in the internal structure and feedback mechanism of
108 the farming system into a desired direction in response to either severe shocks or enduring
109 stress that make business as usual impossible. Deliberate transformation requires resilience

110 thinking, first in assessing the relative merits of the current versus alternative systems in
111 potentially more favourable stability domains (i.e., a domain where a system is robust within
112 certain thresholds of control variables), and second in fostering resilience of the new
113 development trajectory (i.e., towards an alternative, transformed system) and the new basin
114 of attraction (i.e., a system with a more sustainable stability domain) (Folke et al., 2010).

115 Based on the framework by Meuwissen et al. (2019) a range of quantitative and qualitative
116 methods was employed to investigate sustainability and resilience in 11 European farming
117 systems (Meuwissen et al., 2022; Meuwissen et al., 2021). Impact assessments often use
118 quantitative models (e.g. Helming et al., 2011; Herrera et al., 2018; Reidsma et al., 2015; Van
119 Ittersum et al., 2008). Quantitative models are useful to analyse current systems based on
120 statistical data (Dardonville et al., 2021; Reidsma et al., 2010; Slijper et al., 2020), and to
121 simulate the impact of specific scenarios on specific indicators (e.g., Herrera et al., 2022), but

122 resilience of farming systems is too complex to be captured by single models (Accatino et al.,
123 2020). For some indicators, accurate data and process knowledge are available, while for others
124 data are lacking, and therefore such indicators are often ignored (e.g. the attractiveness of a
125 rural area for residents and visitors is difficult to capture with quantitative indicators). In
126 addition, to assess resilience, dynamics of multiple processes need to be investigated
127 simultaneously (Kinzig et al., 2006; Walker and Salt, 2012). It has earlier been argued that it is
128 nearly impossible to account for every factor that contributes to resilience both now and in the
129 future, and that using surrogate indicators is more useful than trying to measure resilience itself
130 (e.g. Cabell and Oelofse, 2012; Darnhofer et al., 2010). Qualitative approaches are needed to
131 understand the dynamics of farms and ~~can partly to~~ address the above-mentioned issues
132 (Darnhofer, 2014). Participatory assessments allow to consistently follow all steps required in
133 order to provide a holistic picture (Ashkenazy et al., 2018; Payne et al., 2019; Sellberg et al.,
134 2017; Walker et al., 2002). In addition, in order to follow-up on an assessment and allow for a
135 transition process, farming system actors (stakeholders and the enabling environment; see
136 Meuwissen et al., 2019) need to be part of the assessment (Quist and Vergragt, 2006). Hence,
137 we first assessed sustainability and resilience of *current* European farming systems with a
138 structured participatory method (Paas et al., 2020; Reidsma et al., 2020a), and next, we
139 addressed sustainability and resilience of *future* farming systems in collaboration with relevant
140 actors (Paas et al., 2021a; Paas et al., 2021b).

141 According to stakeholders in the first round of workshops in the selected European farming
142 systems, sustainability and resilience of current systems is low (Paas et al., 2020; Reidsma et
143 al., 2020a). In the first part of the second round of workshops, on future systems, it was
144 concluded that many of the current systems are close to critical thresholds regarding the
145 challenges they face (e.g., droughts, price declines), functions they deliver (e.g., economic
146 viability, biodiversity and habitat) and attributes required for resilience (e.g., social self-

147 organization) (Paas et al., 2021a). A quantitative modelling study confirmed closeness to critical
148 thresholds for the Dutch case study, and showed that only actively implementing strategies
149 allowed the system to remain resilient (Herrera et al., 2022). However, across Europe strategies
150 have, so far, mainly focussed on robustness, and lack attention for adaptability and
151 transformability (Buitenhuis et al., 2020b; Paas et al., 2020; Reidsma et al., 2020a).

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

159 **2 Material and methods**

160 **2.1 Participatory assessment of resilience and sustainability of farming systems**

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

164

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	Government	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			

165

166

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

176 FoPIA-SURE-Farm I (Nera et al., 2020; Paas et al., 2020; Reidsma et al., 2020a), was conducted
177 in the 10 case studies presented in Table 1 and a case study on dairy farming in Flanders,
178 Belgium. In each case study, one workshop of around six hours was held between November
179 2018 and March 2019. The number of participants differed between 6 and 26, and represented
180 farmers, industry, NGOs, government, research and advice, and others, with a total of 184
181 participants (Paas et al., 2020). In brief, the workshops focused on: 1) ranking the importance
182 of functions (private and public goods) and selecting representative indicators for these
183 functions; 2) scoring the current performance of the representative indicators; 3) sketching
184 past dynamics of main representative indicators of functions; 4) identifying which challenges
185 caused these dynamics and which strategies were implemented to cope with these challenges;
186 5) assessing level of implementation of identified strategies and their potential contribution to
187 the robustness, adaptability and transformability of the farming system; and 6) assessing the
188 level of resilience attributes and their potential contribution to the robustness, adaptability and
189 transformability of the farming system.

190 In FoPIA-SURE-Farm II (Paas et al., 2021b), a workshop of around four hours was held between
191 November 2019 and March 2020 in 9 case studies, and in 1 case study (FR-Beef) a desk study

192 was performed, as the COVID-19 crisis prevented the realization of the workshop. In the desk
193 study, inputs from stakeholders and experts, based on earlier work and literature, were
194 considered. Only specific results from this case study are included. A desk study was also
195 performed in the aforementioned Belgian case study, but this case is excluded from the current
196 paper as it focused on the status quo only. The number of participants ranged between 5 and
197 22, with a total of 128 participants (Table 1; Paas et al., 2021a). The first half of the workshop
198 was focused on forecasting in relation to maintaining the status quo and system decline in case
199 critical thresholds would be exceeded, and results for the 10 European farming systems and
200 the one in Belgium are described in Paas et al. (2021a). This forecasting approach included an
201 assessment of: 1) the development of current systems; 2) identification of critical thresholds
202 whose exceedance can lead to large and permanent system change; 3) an assessment of the
203 developments when critical thresholds are exceeded. These steps build on FoPIA-SURE-Farm I,
204 as the previously identified most important functions, challenges and resilience attributes were
205 considered for this assessment.

206 The second half of the workshop was focused on alternative systems and strategies to achieve
207 these, using a backcasting approach (Figure 1; this paper). The essence of backcasting consists
208 of ~~generating-creating~~ desirable sustainable future visions, followed by looking back at how
209 these desirable futures can be achieved, by ~~and turning these, through backcasting analysis,~~
210 ~~design activities and analysis, into follow-up agendas,~~ planning for actions and the realisation
211 ~~of~~ ing follow-up activities and developing strategies leading to that desirable future (Quist and
212 Vergragt, 2006). The backcasting approach included the remaining steps of FoPIA-SURE-Farm
213 II: 4) participatory identification of desired alternative systems towards 2030 and their
214 expected improved performance of sustainability and resilience; 5a) participatory identification
215 of strategies to achieve those alternative systems. The evaluation phase included 6) an
216 assessment by researchers on the compatibility of alternative systems with the developments

217 of exogenous factors as projected in different future scenarios (for more detail, see section
218 2.2).

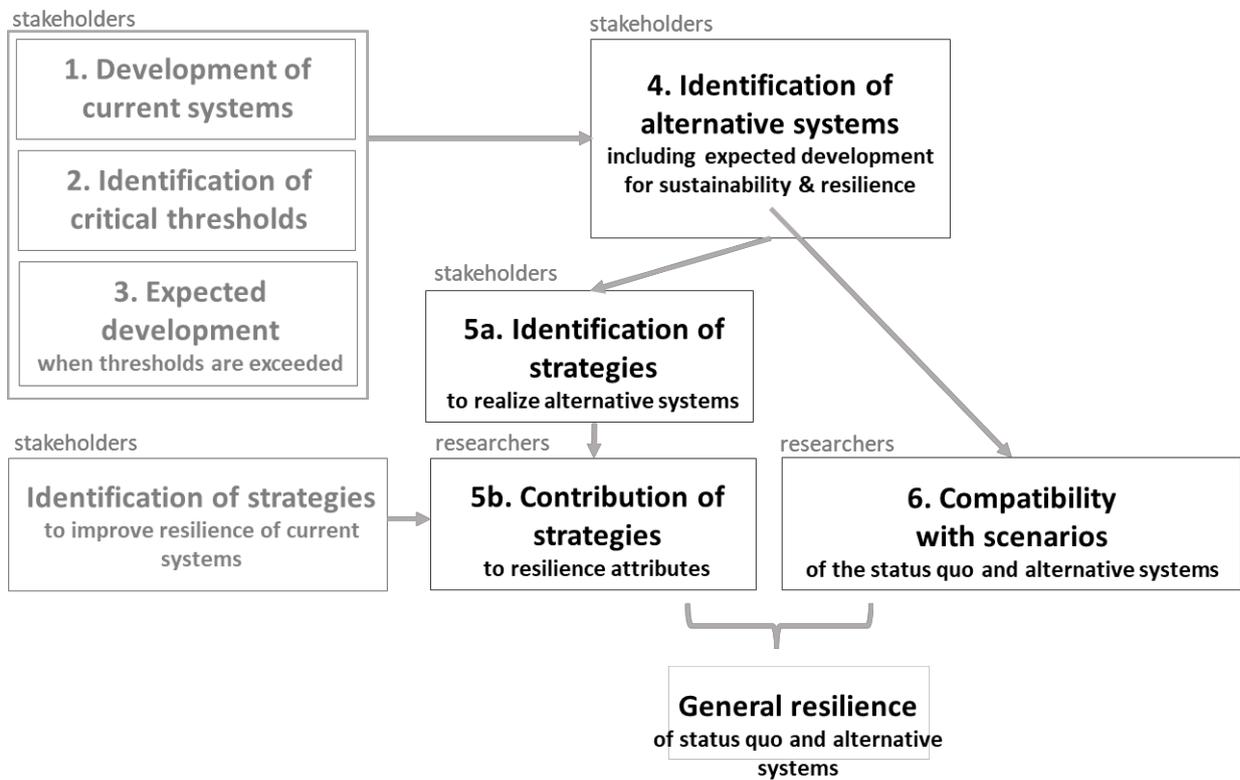
219 Methods and results of all six steps of FoPIA-SURE-Farm II are described in detail for extensive
220 sheep farming in Huesca, Spain, in Paas et al. (2021b); Paas et al. (2021b) present results from
221 the first part across European farming systems, providing forecasts for current systems; ~~and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

229 2.2 Backcasting to design and evaluate alternative systems and strategies

230 Starting with step 4 of FoPIA-SURE-Farm II, we present the identification of alternative systems
231 for the future (Figure 1). All participants in the workshops were asked individually to envisage
232 one or more alternative systems they desired towards 2030 if challenges, functions and/or
233 resilience attributes would cross critical thresholds. Stakeholders were asked for desired
234 transformations, but adaptations were also accepted. Next, in a plenary session in each case
235 study workshop an inventory was made on common alternative systems. Suggestions by
236 individuals were grouped into 2-4 alternative systems. These were considered to be potential
237 future systems, along with maintaining status quo, and system decline (when essential
238 requirements are not met), which serve as a reference.

239 For the cross-case study comparison, alternative systems were categorized according to the
240 most important direction that an alternative system is taking (e.g., specialization), according to

241 the interpretation of the research team in each case study. Categories are hence not mutually
 242 exclusive and alternative systems can have elements of multiple categories. The categories that
 243 came forward in this study are also not exhaustive in the sense that they do not cover all
 244 directions that alternative systems can take.



245
 246 Figure 1. Steps in the backcasting approach of FoPIA-SURE-Farm II to identify alternative systems that contribute
 247 to sustainability and resilience, and to identify associated strategies and developments in future scenarios that
 248 contribute to general resilience. Step 4-6 (in black) refer to backcasting and are addressed in this paper. Step 1-3
 249 (in grey) refer to the forecasting part of FoPIA-SURE-Farm II, which serves as input for the assessment, together
 250 with- 'Identification of strategies to improve resilience of current systems' coming from FoPIA-SURE-Farm I. Step
 251 1-5a are stakeholder-based, and step 5b and 6 are researcher-based.

252 Subsequently, stakeholders were divided in small groups and within each group one alternative
 253 system was discussed (or in subsequent sessions when the number of participants was too
 254 small) with regard to main function indicators, resilience attributes and enabling conditions. A
 255 selected set (based on FoPIA-SURE-Farm I) of main function indicators and resilience attributes
 256 was discussed per case study (see Table SM1.5 of Paas et al., 2021b) as critical system changes

257 are expected to be determined by a small set of key variables (Kinzig et al., 2006).
258 Developments were classified as strongly negative (-2), moderately negative (-1), no impact (0),
259 moderately positive (+1) and strongly positive developments (+2). For the synthesis across case
260 studies, the minimum and maximum of expected developments per function (eight in total)
261 and resilience attribute (13 in total) were evaluated and translated into arrows with the same
262 meaning. These were compared with the average expected developments for the status quo
263 and system decline (Paas et al., 2021a).

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

271 A farming system can be resilient to specific challenges (specified resilience), and strategies can
272 be implemented to deal with such challenges, but this does not necessarily imply that the
273 farming system is capable to deal with the unknown, uncertainty and surprise (general
274 resilience). General resilience can be judged based on the presence of resilience attributes
275 (Meuwissen et al., 2019; Cabell and Oelofse, 2012). An additional step 5b was therefore
276 included to assess the impact of strategies on general resilience. After the workshops,
277 researchers assessed the contribution (either yes or no) of the identified past and future
278 strategies to 22 resilience attributes (see Appendix B for full description). In the assessments
279 with stakeholders, 13 out of these 22 were selected to be discussed, but researchers were
280 assumed to be able to address all 22, allowing ~~both a more holistic picture and a judgement~~
281 ~~regarding the completeness of the selected list~~ to assess which ones from the full list were most

282 important, (also in comparison to the selected 13). Similar to Soriano et al. (2020), resilience
283 attributes were inferred based on statements regarding strategies, using the definition,
284 implication and characteristics of the attributes (Appendix B). The 22 attributes are associated
285 to the 5 general resilience principles (system reserves, tightness of feedbacks, diversity,
286 modularity and openness; Appendix B; Meuwissen et al., 2019). The first and last author of this
287 paper did a first assessment across all case studies, this was checked per case study by case
288 study partners, and evaluated again by the first ~~two and last~~ authors. Results were synthesized
289 based on the relative share of strategies contributing to a resilience attribute, where the
290 contribution of future strategies to reach alternative systems was compared with (past)
291 strategies implemented for current systems.

292 General resilience also relates to the compatibility of farming systems with ~~different future~~
293 ~~scenarios~~ external factors. Some resilience attributes relate to the farming system itself, and
294 some to the enabling environment, and the latter is influenced by scenario narratives. Mitter
295 et al. (2019, 2020) developed five scenarios for European agriculture and food systems, called
296 Eur-Agri-SSPs. These scenarios are plausible and internally consistent views of the future and
297 are in line with the Shared Socio-Economic Pathways (SSPs) as developed for the climate
298 change research community. ~~They and~~ include Eur-Agri-SSP1 – Agriculture on sustainable
299 paths, Eur-Agri-SSP2 – Agriculture on established paths, Eur-Agri-SSP3 – Agriculture on
300 separated paths, Eur-Agri-SSP4 – Agriculture on unequal paths, and Eur-Agri-SSP5 – Agriculture
301 on high-tech paths. Table 3 of Mitter et al. (2020) presents storyline elements and directions
302 of change for the five Eur-Agri-SSPs (see also: [https://eur-agri-ssps.boku.ac.at/eur-agri-ssps-](https://eur-agri-ssps.boku.ac.at/eur-agri-ssps-2/)
303 2/).

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

307 ~~alternative systems~~, case study partners indicated how important an increase in the scenario
308 elements (related to the sections Population, Economy, Policies & institutions, Technology and
309 Environment & Natural resources) as proposed by Mitter et al. (2020) was, where 0 is not
310 important, 1 is somewhat important and 2 is very important. Expected developments of
311 scenario elements were based on Mitter et al. (2020), with -1, 0 and 1 indicating negative, no
312 and positive changes, respectively. Multiplication of the importance of developments for future
313 systems with expected developments of scenario elements was used as an approximation for
314 compatibility. Final compatibility scores per future system per scenario was an average of the
315 overall section scores, where values -1 to -0.66 imply strong incompatibility, -0.66 to -0.33
316 moderate incompatibility, -0.33 to 0 weak incompatibility, 0 to 0.33 weak compatibility, 0.33
317 to 0.66 moderate compatibility, and 0.66 to 1 strong compatibility. An example for ES-Sheep is
318 presented in Paas et al (2021c). For the comparison across case studies, compatibility scores
319 per Eur-Agri-SSP were averaged per category of the alternative systems.

320

321 **3 Results**

322 **3.1 Alternative farming systems**

323 Many desired alternative systems are adaptations rather than transformations of current
324 systems (Table 2; see Appendix A for details). For example, in NL-Arable, starch potato
325 production is at the core of the farming system, and stakeholders had difficulties identifying
326 alternatives without starch potatoes. Similarly, in ES-Sheep, alternatives identified what is
327 needed to keep sheep farming. Integration and diversification were emphasized in many
328 alternatives, but changes in the main products were not envisaged. Some systems can be
329 considered transformative considering the change in intensity of production. For example, the

330 'desirable system' in UK-Arable is supposed to be regenerative. The local organic farming
331 system in PL-Horticulture is a real transformation, as it changes the whole food system.

332 The alternative systems could broadly be grouped in eight categories with three main
333 directions: 1) intensification / specialization / technology / product valorization with a focus on
334 improving production and economic functions and attributes; 2) collaboration / attractive
335 countryside, with a focus on improving social functions and attributes; and 3) diversification /
336 organic / nature friendly with a focus on improving environmental functions and attributes. In
337 relatively more extensive systems like DE-Arable&Mixed, RO-Mixed, ES-Sheep, FR-Beef and PL-
338 Horticulture, alternative systems focused on intensification or specialization were seen as
339 relevant and viable options. Also in SE-Poultry, further intensification was considered as an
340 option. Many case studies considered alternatives which focused on technology development,
341 where generally new technologies should also allow for improving the maintenance of natural
342 resources and biodiversity (e.g. precision agriculture in NL-Arable, high-tech extensive
343 production in ES-Sheep, robots in SE-Poultry). In several case studies, alternatives focusing on
344 collaboration among actors in- and outside of the farming system were specifically identified,
345 emphasizing the need for social interaction in order to improve other functions, such as food
346 production and maintaining natural resources. Lastly, all case studies identified alternatives in
347 relation to diversification and nature friendly agriculture, focusing on improving environmental
348 functions and attributes (however, for ES-Sheep grouped under technology). In many case
349 studies they~~re~~ were seen as ambitious and subject to many enabling conditions.

350 Clearly, the categories are not mutually exclusive, e.g. organic / nature friendly could be
351 combined with a change towards diversification (NL-Arable) or specialization (PL-Horticulture).
352 In most case studies, alternative systems were perceived as compatible with one another at
353 the same time at farm and/or farming system level (BG-Arable, DE-Arable&Mixed, NL-Arable,

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

356

357 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~~
 358 ~~interpretation of the research team in each case study. Categories are hence not mutually exclusive and alternative systems can have elements of multiple categories.~~

Category	Case studies										Total ¹ (n)
	BG-Arable	NL-Arable	UK-Arable	DE-Arable&Mixed	RO-Mixed	ES-Sheep	FR-Beef	SE-Poultry	PL-Horticulture	IT-Hazelnut	
Intensification				Intensification		Semi-intensive		Large farms			3
Specialization					Commercial specialization of family mixed farms		Only-for-export production		Horticulture farming		3
Technology	Innovation and technology	Precision agriculture				Hi-tech extensive		Robots	Shelter farming	Technological innovation	6
Product valorization	Processing and increasing added value						Production only for the French market			Product valorization	3
Collaboration	Collaboration	Collaboration & water			Cooperation / multifunctionality						3
Attractive countryside				Better societal appreciation			Development of tourism			Sustained demand (high and stable prices)	3
Diversification	Crop diversification	Alternative crops	Likely system		Alternative crops / livestock			Self-sufficiency fodder			5
Organic / nature friendly		Nature-inclusive	Desirable system	Organic farming	Organic agriculture				Local organic farming	Eco-friendly agriculture	6
Total (n)	4²	4	2	3	4	2	3	3	3	4	32

359 ¹For FR-Beef, a desk study with researchers was conducted instead of a workshop with stakeholders.

360 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.

361 3.2 Development of future systems

362 Future systems include maintenance of the *status quo*, system decline when critical thresholds
363 are exceeded and the desired alternative systems. ~~In this paper w~~We use the function and
364 attribute development under continued status quo and system decline, which are described in
365 Paas et al. (2021b), as points of reference. ~~For the purpose of reflecting on the results, a~~
366 summary is provided in the remainder of this paragraph. When maintaining status quo under
367 the current challenges, on average indicators representing “economic viability” and
368 “attractiveness of the area” were expected to decrease. In the one case study where “quality
369 of life” was discussed (DE-Arable&Mixed), the provision of this function was also expected to
370 largely decrease. On average, for the continued status quo, no large negative changes were
371 expected for resilience attributes, except for “reasonably profitable” and “appropriately
372 connected with actors outside of the system”. When critical thresholds would be exceeded,
373 and system decline would take place, almost all functions and attributes were expected to be
374 negatively affected.

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

381 Minimum and maximum ~~positive~~ developments of farming system functions in alternative
382 systems indicate that for most functions at most-best moderate improvements are expected
383 (Table 3; Appendix C). For “food production”, “natural resources” and “biodiversity & habitat”,
384 minimum developments were expected to be stable, suggesting that these functions cannot be
385 improved in all alternative systems. For “quality of life” (evaluated once) and “biodiversity &
386 habitat” (evaluated four times), the average maximum development is expected to be strongly
387 positive, while the average minimum development is expected to be negative and stable,
388 respectively. This indicates that for these functions, alternative systems seem to take different
389 directions, and stakeholders foresee trade-offs.

390 Under alternative systems, “food production” is perceived to at least not change and at most
391 moderately improve. For “economic viability” negative developments under status quo are
392 expected to at least be countered by alternative systems and at most be turned into moderate
393 positive developments. For “natural resources”, expected stability under status quo across case
394 studies is expected to become at least slightly improved and at most moderately improved by
395 alternative systems. In UK-Arable, negative developments for indicators representing “quality
396 of life” and “biodiversity & habitat” were expected to continue in the “likely” alternative
397 system. In multiple case studies, some alternative systems resulted in negative developments
398 for “food production” (BG-Arable), “bio-based resources” (DE-Arable&Mixed, RO-Mixed),
399 “economic viability” (BG-Arable and SE-Poultry) and “natural resources” (SE-Poultry, NL-
400 Arable), implying a trade-off as overall performance of main indicators was expected to
401 improve.

402 Table 3. Developments of system indicators per function and resilience attributes for the status quo, system
 403 decline and minimum and maximum developments in alternative systems. Arrows down (↓) and brown imply
 404 strong negative, down-right (↘) and orange moderate negative, straight (→) stable, right-up (↗) and light green
 405 moderate positive, and up (↑) and dark green strong positive developments, with others in-between.

Function/resilience attribute	Name	Number of times discussed	Expected average developments in future systems			
			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	→	↘	→↘	↗↑

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

407 Minimum and maximum developments were expected to be stronger for resilience attributes
 408 than for functions. This suggests that stakeholders have more trust in the ability to improve
 409 resilience attributes than in the effect this will have on improving the performance level of

410 system functions. In particular, “production coupled with local and natural capital” and
411 “infrastructure for innovation” were often evaluated and expected to show moderate to strong
412 positive developments in proposed alternative systems. The maximum was high, but also the
413 minimum was relatively high, suggesting that stakeholders considered these attributes as
414 prerequisites for alternative systems. Also “socially self-organized” and “appropriately
415 connected with actors outside of the system” showed large potential for improvement in
416 multiple alternative systems.

417 **3.3 Identification of past and future strategies**

418 Strategies that were mentioned by participants as being implemented in the past and
419 suggested for alternative systems (see Appendix D for a complete overview) had different
420 degrees of specificity: some strategies were umbrella strategies and overarched a set of more
421 specific challenges, while other strategies were very specific actions and linked to one domain.
422 Across case studies, 112 strategies were identified as being implemented in the past to enhance
423 resilience of current systems, and an additional 88 were identified to reach alternative systems.
424 Agronomic strategies included diversification, implementation of more technology, and
425 improved knowledge and research on crops and livestock (NL-Arable, ES-Sheep, SE-Poultry, DE-
426 Arable&Mixed, RO-Mixed). In many cases, these were strategies already employed by part of
427 the farms, which can only be up-scaled in combination with economic, institutional and social
428 strategies.

429 While in the past, strategies to remain resilient focused on the economic domain, when
430 envisaging future strategies attention shifted to other domains. Strategies that had been
431 important in the past, such as increasing farm size and intensity, do not contribute to most
432 alternative systems. However, in many case studies, economic strategies such as diversification
433 of income sources (ES-Sheep, FR-Beef, RO-Mixed, UK-Arable) remained ~~relevant~~ important in
434 at least one of the alternative systems. Economic strategies thus remained relevant, but the
435 nature changed. For example, in NL-Arable, for three out of four alternative systems economic
436 strategies were identified, but the nature of the strategies shifted from scaling up production
437 and cost reduction towards developing a new business model.

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

448 Strategies primarily aimed at the social domain were mentioned in all case studies, except for
449 SE-Poultry. In SE-Poultry, stakeholders argued that knowledge sources were available and that

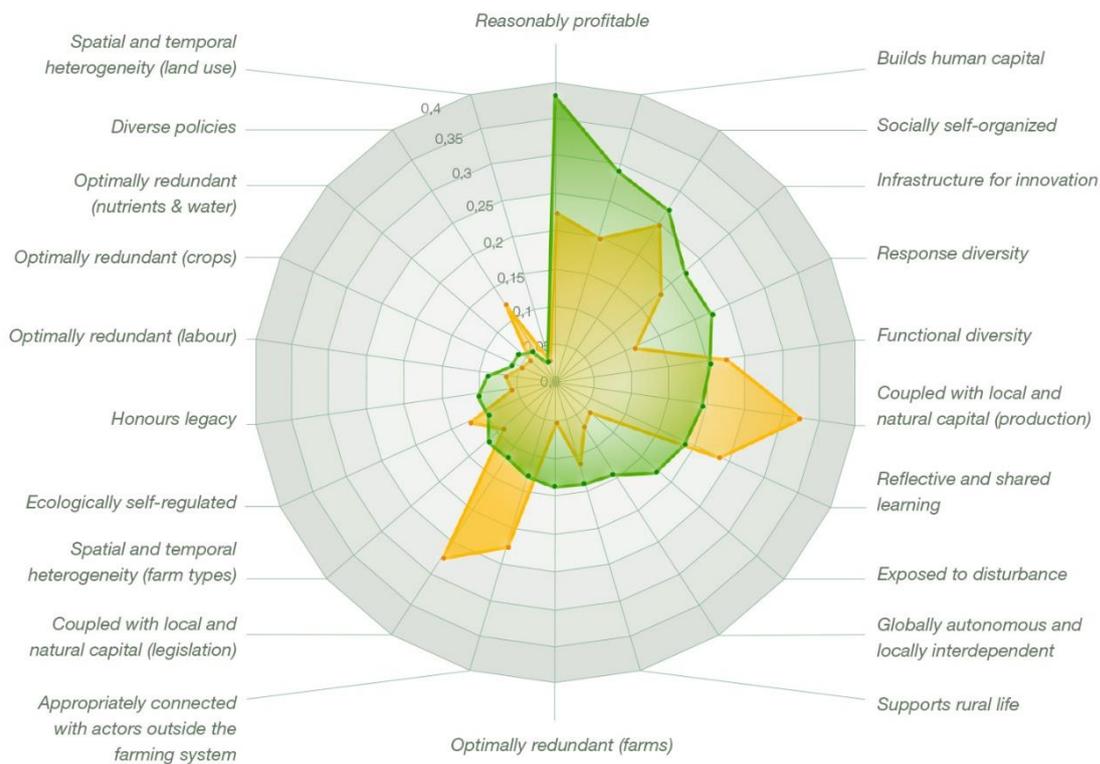
450 these were used to a good extent. Important strategies in the social domain included
451 cooperation and/or knowledge sharing among farming system actors (in a value chain and/or
452 cooperative) (all case studies having socially oriented strategies), and learning, education
453 and/or awareness raising strategies for actors inside the farming system (UK-Arable, NL-Arable,
454 IT-Hazelnut, BG-Arable, RO-Mixed) or aimed at producer-consumer connections (PL-
455 Horticulture, NL-Arable, ES-Sheep).

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

459 **3.4 How do past and future strategies impact resilience attributes?**

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

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



483

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

488 3.5 Compatibility of farming systems with future scenarios

489 Although different strategies are needed for different alternative systems, alternative systems
 490 generally thrive in the same scenario. Most future systems, including maintaining the status
 491 quo, are most compatible with Eur-Agri-SSP1 "Sustainable paths" (Table 4; Appendix E). This is
 492 mainly due to favourable developments regarding policies and institutions and technology,

493 which are environment-focused (e.g., agri-environmental payments increase), corresponding
494 with enabling conditions and strategies for most future systems (Appendix E). Also,
495 developments in the population may increase compatibility as citizen environmental awareness
496 is expected to increase and the rural-urban linkages to be strengthened. This is however not
497 important for all alternative systems. For instance, alternative systems that focus on
498 specialization in PL-Horticulture and RO-Mixed depend less on developments related to
499 population. For most arable systems, developments regarding the environment and natural
500 resources are also favourable and help to avoid further degradation beyond critical thresholds,
501 e.g. regarding soil quality. For arable systems, the need for improving soil quality also explains
502 lesser compatibility with other Eur-Agri-SSPs, where maintenance of natural resources is
503 expected to stay stable or even decline. It should be noted that too much attention for
504 environmental performance might threaten certain crops that under conventional cultivation
505 depend on crop protection products, e.g. potato. The most compatible development would be
506 towards alternative systems primarily driven by organic / nature friendly production under Eur-
507 Agri-SSP1, but also product valorization and intensification seem to be very compatible with
508 this scenario.

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

Category	future systems	Future systems [#]	Average compatibility score with Eur-Agri-SSPs				
			SSP1 "Sustainable"	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 Product valorization	6	0.61	0.30	-0.52	0.21	0.25	
Collaboration	2	0.68	0.26	-0.79	0.00	0.23	
Attractive countryside	3	0.63	0.26	-0.75	0.16	0.24	
Diversification	2	0.50	0.43	-0.62	0.26	0.52	
Organic / nature friendly	5	0.69	0.24	-0.50	0.07	0.14	
	6	0.71	0.36	-0.74	0.10	0.21	
Average¹		0.62	0.32	-0.60	0.15	0.26	

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

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

522 compatible, while also the systems emphasizing an attractive countryside (specifically in IT-
523 Hazelnut) are moderately compatible.

524 In Eur-Agri-SSP3 “Separated paths”, most rural-urban linkages, infrastructure, export, trade
525 agreements, institutions, technology levels and maintenance of natural resources are expected
526 to decline, which is only expected to be compensated by increased commodity prices and direct
527 payments. Eur-Agri-SSP3 seems, therefore, most incompatible with most future systems in all
528 case studies, especially because many farming systems currently produce for international
529 markets and/or depend on technology and maintenance of remaining natural resources. SE-
530 Poultry is an exception to this, because of the current experienced mismatch between Swedish
531 national food production quality requirements and EU free trade agreements. SE-Poultry is
532 mainly producing for its own national market. Closing borders and decreased trade agreements
533 would consequently imply an increase in a competitive advantage over cheaper produced,
534 lower quality products from other countries (under the condition that technology and feed are
535 also locally produced). Loss of competitive advantage because of mismatches between
536 regulations was also mentioned by participants in DE-Arable&Mixed and PL-Horticulture, but
537 only to a limited extent.

538 Eur-Agri-SSP4 “Inequality paths” shows a mix of positive and negative developments. Storyline
539 elements in relation to population, such as rural-urban linkages are expected to decrease while
540 technology levels are expected to go up. Elements related to economy and policies and
541 institutions are showing both positive and negative developments. In Eur-Agri-SSP4, further
542 depletion of natural resources is expected, but probably at a slower rate due to increased

543 resource use efficiency. Altogether, future systems are weakly compatible with the
544 developments in Eur-Agri-SSP4. Alternative systems primarily driven by intensification,
545 specialization or technology seem to be most compatible with this SSP.

546 Alternative systems seem only weakly compatible with Eur-Agri-SSP5 “High-tech paths”. In Eur-
547 Agri-SSP5, technology levels will generally increase, but not necessarily made available to
548 agriculture, which is partly why alternative systems primarily driven by technology are not the
549 most compatible alternatives.

550 **4 Discussion**

551 **4.1 Contribution of alternative systems and associated strategies to sustainability and** 552 **resilience**

553 The main aim of this study was to identify sustainable and resilient alternative farming systems
554 and associated strategies for European farming systems. Results showed that when maintaining
555 status quo, specifically the functions “economic viability”, “attractiveness of the area” and
556 “quality of life” were judged to be at risk. Interacting thresholds regarding these functions may
557 lead to negative feedback loops (Paas et al., 2021a). Also resilience attributes “reasonably
558 profitable” and “appropriately connected with actors outside of the system” were expected to
559 develop negatively. Scientific literature often focuses on negative environmental impacts of
560 agricultural systems (e.g., Campbell et al., 2017; Springmann et al., 2018), and policies are
561 formulated to improve this, but deteriorating economic and social performance is of more
562 immediate concern for stakeholders from within the farming system. While social unrest (van

563 der Ploeg, 2020) suggests that farmers are not willing to change towards more sustainable
564 systems as demanded by society and policy, they are mainly concerned that additional requests
565 regarding environmental performance will render them economically unsustainable.

566 Desired alternative systems paid specific attention to the declining functions, but also to
567 improve “biodiversity and habitat”. While in some case studies it was argued that elements of
568 different alternative systems could be combined, in others they moved in different directions,
569 with opposite impacts on social and environmental functions. Stakeholder input provides good
570 starting points to understand which options provide most opportunities, but it should be noted
571 that identified alternative systems are rather adaptations than transformations.

572 Transformations require a change in norms and values (Rotmans, 2014), while stakeholders are
573 attached to and depend on the identity of a system, and specifically farmers largely focus on
574 short-term economic viability (Reidsma et al., 2020a). As long as economic viability is at risk, it
575 may however be argued that this is logical (Paas et al., 2021a). Stakeholders clearly have
576 attention for environmental and social functions, and larger transformations may gradually
577 evolve via a combination of incremental adaptation and ‘small wins’ (Termeer and Dewulf,
578 2019). Small wins are radical, but start at local level, and provide visible results and steps
579 forward towards a shared ambition. Stakeholders may not have trust in radical transformations,
580 but when they observe that strategies in the agronomic, economic, institutional and social
581 domain can be combined to make ~~incremental adaptations~~ a change, this may also result in
582 changed norms and values and result in larger transformations in the longer term (De Kraker,

583 2017). New business models, as mentioned by multiple stakeholders in our workshops, are
584 needed to tackle long-term challenges.

585 With regard to resilience attributes, strategies in the past specifically enhanced “reasonably
586 profitable”, and to a lesser extent “builds human capital”, “socially self-organized”,
587 “infrastructure for innovation”, “response diversity”, “functional diversity” and “production
588 coupled with local and natural capital”. ~~This result is in line with Soriano et al. (Reidsma et al.,
589 2020a; Soriano et al., 2023), who found that according to stakeholders in a different set of focus
590 groups, the actors in farming systems in Europe have contributed to the resilience attributes
591 “builds human capital”, “response diversity”, “socially self-organized and “reflecting and shared
592 learning” by implementing strategies to deal with challenges threatening farming systems.~~

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

602 Strengthening the resilience attribute “infrastructure for innovation” was important in the past
603 and remains so for future systems. This resilience attribute is perceived by stakeholders to be
604 particularly important for transformability (Paas et al., 2020; Reidsma et al., 2020a). ~~While~~
605 ~~g~~Governments need to contribute to transformability by developing long-term visions and
606 continuous and improved legislation, ~~it has been suggested that the role of the enabling~~
607 ~~environment and also their role and of other actors in the enabling environment~~ in investments
608 and risk-management is crucial (Mazzucato, 2018)~~(Mazzucato, 2018)~~. Translated to resilience
609 attributes, governments need to ensure “infrastructure for innovation” by developing
610 “diverse policies” (with less focus on robustness, and more on transformability), and investing
611 in risky strategies to make alternative directions “reasonably profitable”. The EU Rural
612 Development Programmes (RDP) provide good examples; in NL-Arable for example, these
613 subsidies stimulate innovation, and also allow to be “appropriately connected with actors
614 outside the farming system” (see [https://www.pop3subsidie.nl/blog/kennisbank/](https://www.pop3subsidie.nl/blog/kennisbank/veenkolonien-samenwerking-voor-innovaties/)
615 [veenkolonien-samenwerking-voor-innovaties/](https://www.pop3subsidie.nl/blog/kennisbank/veenkolonien-samenwerking-voor-innovaties/); in Dutch).

616 When assessing compatibility with future scenarios, some systems seem more resilient than
617 others. However, none of the systems can cope with all kinds of challenges. Especially in Eur-
618 Agri-SSP3, according to the scenario narrative, many resilience attributes are eroded. Enabling
619 conditions for maintaining status quo and reaching desired alternative systems are thus not
620 present in Eur-Agri-SSP3. Overall, we could, therefore, not identify “robust strategies” in the
621 sense that they aligned with all possible scenarios (see e.g. Kok et al., 2011; van Vliet and Kok,
622 2015). Instead, we argue that for European farming systems, EU policies should be directed at

623 avoiding certain scenarios, and stimulate the development towards a scenario that enables the
624 building of local and natural resources, the development of social self-organization and
625 technology that in turn will support the functions and resilience attributes previously
626 mentioned. ~~↳~~Currently, the Eur-Agri-SSPs of Mitter et al. (2020) do not describe a scenario
627 containing all these elements, while alternative farming systems seem mostly compatible with
628 SSP1 “Sustainable paths”. This would imply that, when taking SSP1 as a point of departure,
629 which seems the case with the new Farm to Fork strategy, EU policies should specifically study
630 the possibilities to strengthen institutional, social, economic and technological developments
631 in this specific scenario. At local level, individual farming systems should be encouraged to
632 improve their compatibility with macro-level developments. As the compatibility scores are
633 averages of different macro-level developments (e.g. population, technology) of the narratives,
634 farming systems may be compatible with some, but not with other developments. A strategy
635 can thus focus on improving the compatibility with certain developments; even though at
636 European level such a development is not compatible, at local level actors can change this, at
637 least to some extent in their local context. The latter also refers again to the “small-wins”
638 approach (Termeer and Dewulf, 2019): small, meaningful steps with tangible results can be
639 energizing and lead to transformation at higher levels.

640 **4.2 Resilience attributes**

641 Resilience attributes considered were based on Cabell and Oelofse (2012), and adapted in the
642 context of the SURE-Farm project (Paas et al., 2019; Appendix B). “Infrastructure for
643 innovation” and “Support rural life” were added, and several attributes were split and adapted

644 to make them more specific for farming systems. The list of 22 attributes was however too long
645 to discuss with stakeholders, and therefore only the main 13 were assessed during the FoPIA-
646 SURE-Farm I workshops (Paas et al., 2021a; Nera et al., 2020; Reidsma et al., 2020). This implied
647 that some attributes specifically emphasized by other authors like Tittonell (2020), including
648 “ecologically self-regulated”, “reflective and shared learning”, and “builds human capital”, were
649 omitted. While these attributes do overlap with others, Figure 2 also showed that stakeholders
650 do have attention for strategies related to these attributes. On the other hand, Tittonell (2020)
651 omitted “reasonably profitable” from his main list, while this attribute appeared to be the most
652 important according to our assessments (see also Soriano et al., 2020).

653 While the number of resilience attributes that need to be considered may be enlarged or
654 reduced, resilience attributes are suggested to be synergistic in nature, implying positive
655 interactions (e.g., Nemeč et al., 2014; Walker and Salt, 2012) or even purposely reinforcing
656 processes (Bennett et al., 2005). Under influence of the current institutional environment
657 and/or current socio-technological regime with a focus on production and economic functions,
658 synergistic effects seem to be diminished, which results in a one-sided approach to resilience.
659 On the other hand, a strong focus on agro-ecological transition of farming systems (e.g.
660 Tittonell, 2020), may result in an overemphasis on diversity and redundancy, neglecting the
661 importance of (short-term) economic viability. Farming systems are embedded in socio-
662 technological regimes, and sustainability and resilience of farming systems also depend on the
663 context, as also shown in the scenario compatibility analysis (section 3.5). Synergistic effects
664 imply co-evolution. However, to realize resilience attributes, claims on the same resources

665 might be made. At the same time, resilience attributes may ensure the availability of resources
666 in the long term. A key question is thus how institutions should govern investment in and the
667 use of resources and capacities (Mathijs and Wauters, 2020).

668 4.3 Participatory assessment

669 Qualitative approaches to understand resilience are promoted (e.g. Darnhofer et al., 2010;
670 Cabell and Oelofse, 2012; Darnhofer, 2014; Walker et al. 2002; Ashkenazy et al. 2018; Payne et
671 al. 2018; Sellberg et al. 2017). However, participatory approaches have their caveats.
672 Participatory exercises are strongly influenced by existing social relationships, and information
673 is shaped by relations of power and gender, and by the investigators themselves (Mosse, 1994).
674 Therefore, it has been suggested that participatory assessments need to be complemented by
675 other methods of ‘participation’ which generate the changed awareness and new ways of
676 knowing, which are necessary for bottom-up innovation and change (Mosse, 1994; Timilsina et
677 al., 2020). Participatory approaches do not allow to understand individual thoughts, feelings,
678 or experiences (Hollander, 2004) and need to be complemented by interviews with individuals
679 to generate meaningful results. For this reason, Further, different types of stakeholders were
680 consulted in each case study, and the synthesis of results across case studies averaged out
681 opinions of individuals or case study specific results. In addition, the FoPIA-SURE-Farm
682 approach itself did not solely rely on group discussions, but also included individual assignments
683 in order to collect knowledge and perceptions of individuals. ~~Lastly, in addition~~ Furthermore, part
684 of the work was executed by case study researchers, to ensure good understanding of the
685 concepts. Lastly, different types of stakeholders were consulted in each case study, and the

686 synthesis of results across case studies averaged out opinions of individuals or case study
687 specific results.

688 In addition,

689

690

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

694 Whereas the current assessment was ~~mainly~~ based on FoPIA-SURE-Farm I and II to ensure
695 consistency, these methods were complemented with other methods and triangulation took

696 place to assess consistency of results. For example, ~~we used~~ system dynamics modelling,

697 where we combined stakeholders' perspectives with theories and empirical evidence, to found

698 ~~in the literature and checked~~ the coherency of perspectives ~~by looking at them from a system~~
699 ~~perspective~~ (Herrera et al., 2022; Reidsma et al., 2020b). We also used statistical modelling to

700 assess specific functions and resilience capacities of EU farming systems (Slijper et al., 2020;

701 Paas et al., 2023). This mixed-methods approach allows a comprehensive insight in current and

702 future sustainability and resilience of EU farming systems (Meuwissen et al., 2022; Meuwissen

703 et al., 2021). ~~Further, different types of stakeholders were consulted in each case study, and~~

704 ~~the synthesis of results across case studies averaged out opinions of individuals or case study~~

705 ~~specific results. In addition, the FoPIA-SURE-Farm approach itself did not solely rely on group~~

706 ~~discussions, but also included individual assignments in order to collect knowledge and~~
707 ~~perceptions of individuals. Lastly, part of the work was executed by case study researchers, to~~
708 ~~ensure good understanding of the concepts.~~

709 With the objective to ~~identify alternative systems to~~ improve sustainability and resilience of EU
710 farming systems, the alternative systems identified in this study should not be seen as the final,
711 but as the starting point. Alongside this bottom-up assessment, top-down assessments were
712 performed with 'critical friends' (participants invited as experts, not as representatives of
713 specific interests) to identify policy recommendations for more resilient farming systems
714 (Buitenhuis et al., 2020a). 'Critical friends' are less bounded to the current situation, and their
715 tendency towards more transformative strategies can complement the more operational focus
716 of the local stakeholders in this study. Also more radical top-down visions of future food and
717 farming systems (Bodirsky et al., 2022; van Zanten et al., 2023) can complement the actor-
718 supported visions, but a participatory process is needed to make a change. Later, The results
719 of the current study and other of all approaches were used to discuss archetypical patterns
720 identified in the various case studies and on how actions in the enabling environment tend to
721 constrain the resilience of farming systems (Mathijs et al., 2022). Based on this, principles and
722 recommendations for an enabling environment that fosters resilience, including
723 transformation, were formulated. Resilience policy dialogues need to continue in the case
724 studies, gathering all relevant actors from the farming system and its environment, based on a
725 shared goal, information and data, a formalised and agreed time frame, and a monitoring and
726 evaluation framework (Mathijs et al., 2022). These dialogues should be accompanied by one-

727 to-one discussions, which are less bounded by social pressure, where ‘miracle questions’
728 (‘imagine that a miracle happens that results in a transformed and ideal agriculture’) can allow
729 to think further out-of-the-box (Moore and Milkoreit, 2020; Young et al., 2023). This should
730 pave the way towards alternative systems, which may become more transformative over time.

731 5 Conclusion

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

741 The resilience of current farming systems is low, as strategies have been mainly focused on
742 strengthening the economic sustainability dimension and robustness resilience capacity. To
743 make a transition to alternative systems and improved resilience, strategies need to
744 simultaneously reinforce economic (less focused on scale enlargement and intensification, but
745 more on developing new business models), environmental (e.g., soil quality, varieties adapted
746 to local climatic conditions, reducing inputs, improving circularity), institutional (e.g.,

747 regulations, rewarding the delivery of public goods) and social (e.g., improving the level of
748 connections of farming system actors with actors outside their system) sustainability
749 dimensions. Maintaining profitability remains important, but it should not get the strong focus
750 as it currently gets in most farming systems.

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

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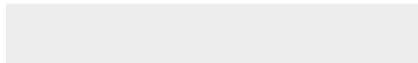
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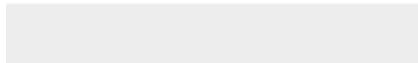




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Declaration of interests

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.