Re-Livestock
RESILIENT FARMING SYSTEMS

# Deliverable 7.1
# Shared Socio-Economic Pathways for the European livestock sector

# Contents



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# Executive Summary

Livestock farming systems may contribute to climate change mitigation and are required to adapt to climate change. At the same time, livestock farming is driven by changes in a multitude of different factors, including agri-food, environmental and climate policies, consumer preferences and demand, costs for livestock production, availability and quality of natural resources, technology development and others. Given the high uncertainty of the future development of these factors, utilizing scenarios allows for a structured management of these uncertainties. In this deliverable, five plausible scenarios for European livestock farming systems (Eur-LFS-SSPs) are presented, consisting of narratives and semi-quantitative development directions of scenario elements. The scenarios follow the logic of the Shared Socio-Economic Pathways (SSPs) and can be distinguished according to two dimensions: challenges for climate change adaptation and challenges for climate change mitigation. The scenarios have been developed by following an established protocol designed to downscale and extend the SSPs for agri-food systems. In the scenario development process, 153 stakeholders were engaged during different working steps: defining scenario elements, defining development directions of the scenario elements, drafting and reviewing the narratives as well as the development directions. Stakeholders were engaged via semi-structured interviews, workshops and group discussions. The Eur-LFS-SSPs are entitled European Livestock Farming Systems in a(n) (1) Sustainable Era, (2) Established Era, (3) Self-Sufficient Era, (4) Unequal but Green Era, and (5) Innovative but Fossil-Fuelled Era. They describe developments of 80 scenario elements clustered along five topics: Population & Urbanization, Policies & Institutions, Economy, Technology, and Environment & Natural Resources. The newly developed scenarios may inform policy-making processes, extension services, teaching and research, for instance, for examining potential levers of change, for developing robust management practices in dealing with change, for identifying arising research questions, and for applying the scenarios in integrated or sustainability assessments.

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# 1. Introduction

## Pressures of Livestock Farming Systems

Livestock farming systems provide outputs for direct consumption (e.g., milk, eggs), multiple use consumption (e.g., manure) and other ecosystem services (e.g., cultural landscape, biodiversity; Accatino et al., 2019; Bengtsson et al., 2019). At the same time, livestock farming systems are subject to considerable pressures resulting from environmental, economic, technological, social and policy changes. For instance, livestock farming systems are required to adapt to climate change (Godde et al., 2021). They have to cope with input and output price variabilities that often lead to more intensive production (Tindale et al., 2024), and technological progress and innovation shape production processes and labour demand (Singh et al., 2022; Thornton, 2010). In Europe, livestock farming is often pursued by family-owned farms (Davidova and Thomson, 2014; Eurostat, 2023) and, thus, faces the related challenge of farm succession (Davidova and Thomson, 2014; Larcher, 2022). The most prominent policy shaping livestock farming systems in the European Union (EU) is the Common Agricultural Policy (CAP; Barnes et al., 2016), which provides subsidies for farmers but also defines environmental standards (Tindale et al., 2024).

While facing pressures, livestock farming systems may also put pressures on other related systems. For instance, livestock farming contributes to climate change as it is a relevant source of non-$CO_2$ greenhouse gas (GHG) emissions, both globally and in the EU (FAO, 2020). Another example are high livestock densities that have resulted in surface water eutrophication and groundwater nitrate enrichment (Leip et al., 2015).

Put differently, livestock farming is relevant for achieving different policy objectives, as specified in the Green Deal, the Farm2Fork strategy or the Biodiversity strategy of the European Commission. Yet, as livestock farming depends on many drivers and the future development of these drivers is uncertain, it also remains uncertain to what extent livestock farming systems can indeed contribute to meeting these policy objectives.

Gouttenoire et al. (2011) define livestock farming systems as follows:

“A livestock farming system is a set of dynamically interacting entities managed by humans to transform resources via domestic animals in various outputs (e.g., milk, meat, wool organic matter) or to serve other goals (based on Landais, 1987).” (p. 1959).

“Livestock farming systems can be defined with different boundaries (Landais, 1987), from production units within the farm (Coléno, 2002) to communities of farmers making use of a common pool of resources over a given territory (Badini et al., 2007).” (p. 1959)

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## Scenarios to deal with uncertainties of future developments

Scenarios outline the key drivers of a particular system in a plausible and consistent manner, addressing the overall aim to deal with future uncertainties (Henrichs et al., 2010; Mitter, 2023). Various scenarios have been developed for agri-food systems, with the Eur-Agri-SSPs, the Shared Socioeconomic Pathways for European agriculture and food systems (https://eur-agri-ssps.boku.ac.at; (Mitter et al., 2020), being a widely used scenario set (e.g., Karner et al., 2024; Nagesh et al., 2023). The Eur-Agri-SSPs present the range of plausible developments of European agri-food systems until 2050 by following the matrix architecture of the global "Shared Socioeconomic Pathways (SSPs)" (O'Neill et al., 2017). Hence, the five scenarios are characterized by varying challenges for climate change mitigation and climate change adaptation, as illustrated in figure 1. In short, the Eur-Agri-SSPs focus on plausible developments of 50 scenario elements (i.e., drivers of the agri-food systems). Thereof, 13 belong to the topic of policies and institutions, including, for instance, the effectiveness of institutions, environmental or food standards, direct payments for agriculture (similar to the first pillar of the CAP of the EU), or public payments for rural development and less-favoured areas (similar to the second pillar of the CAP of the EU). Yet, as the Eur-Agri-SSPs comprehensively describe developments for the agri-food systems, specific aspects related to livestock farming are covered to a limited extent. In response to the pressures of livestock farming systems and related uncertainties, we suggest a sectoral extension of the Eur-Agri-SSPs to derive plausible scenarios for European livestock farming systems in a consistent and structured way.

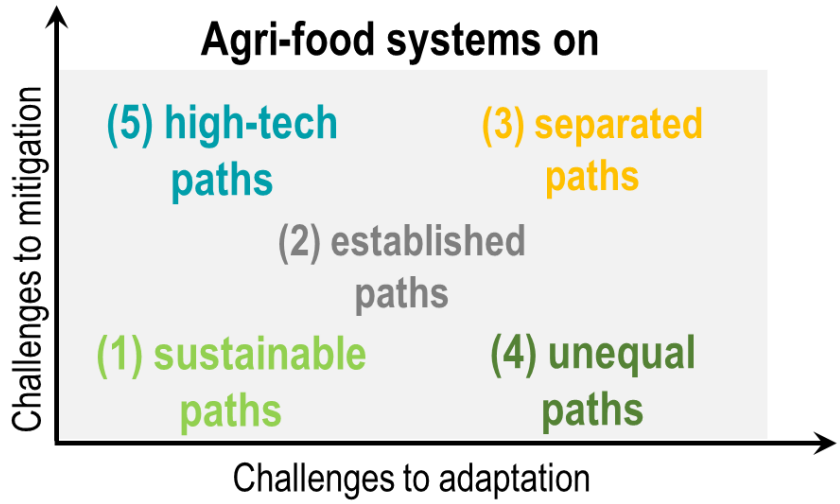


**Figure 1**: Classification of the five Eur-Agri-SSPs along the matrix of challenges to climate change mitigation and adaptation (based on: Mitter et al., 2020).

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# 2. Objectives, Research Questions and Definitions

## Objectives

In the research project Re-Livestock, scenarios are developed in WP7, with task 7.2 focusing on explorative scenarios. The respective objective of this task and this deliverable is to describe alternative plausible future developments for European livestock farming systems, considering the challenges of climate change mitigation and adaptation. Therefore, we aim to derive five Shared Socio-economic Pathways for European livestock farming systems, in short Eur-LFS-SSPs.

## Research questions

In particular, the following research questions are addressed in this deliverable:

- What are the key drivers of European livestock farming systems?
- What are plausible developments of European livestock farming systems following the scenario logic of the SSPs?

## Glossary

A short glossary defines key terms used in this deliverable to ensure a common understanding:

**Scenario:** Scenarios are commonly defined to describe the key drivers of a specific system in a plausible, structured and consistent manner in order to deal with future uncertainties (Henrichs et al., 2010; Mitter, 2023). It should be noted that scenarios are neither forecasts nor predictions but may be useful to deepen the understanding of causal processes, to stimulate innovative thinking, and to enhance decision-making processes (Wright et al., 2013). In this deliverable, we define a scenario such that it consists of (i) a narrative and (ii) a table with the identified scenario elements and their development directions. It should also be noted that scenarios are distinguished from pathways (see definitions provided by the Intergovernmental Panel on Climate Change; https://apps.ipcc.ch/glossary/).

**Narrative:** A narrative of a scenario builds on the scenario elements and their development directions. It is a textual description of how the future may unfold. Narratives usually aim to draw a complete picture and tell a story about the future period. A synonym in the literature is storylines.

**Scenario element:** Scenario elements are the key drivers of a system for which a scenario is developed. Synonyms in the literature are storyline elements or scenario drivers.

**Development direction:** Development direction refers to the development of a scenario element within a particular scenario and time frame. In this deliverable, we distinguish five development directions: a strong increase, a moderate increase, constant development, a moderate decrease and a strong decrease. In our case, the development direction always refers to the status quo of the scenario element (i.e., 2023).

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# 3. Methods

For developing a new set of scenarios for European livestock farming systems, the Eur-LFS-SSPs, we have followed a nested approach (Zurek and Henrichs, 2007) as well as the nine working steps defined in a protocol for scenario development (figure 2 and Mitter et al. 2019). The Eur-Agri-SSPs (Mitter et al., 2020) served as boundary conditions for the scenario development. As depicted with the arrows in figure 2, the scenario development process was iterative for the working step 5, consistency checks, and the working step 7, peer and stakeholder review. The working steps are described in detail later in this section.

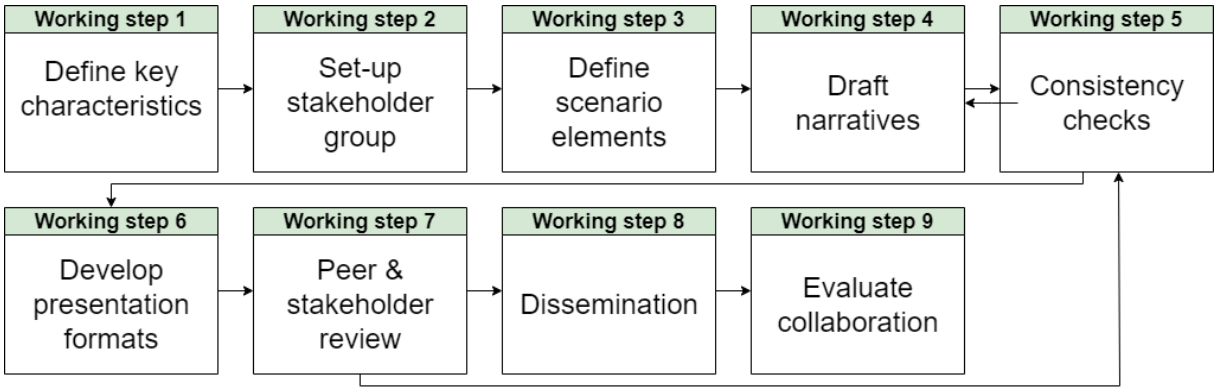


**Figure 2**: Protocol for scenario development applied in Re-Livestock, based on Mitter et al. 2019.

Stakeholders were engaged in several working steps. Figure 3 summarizes who (stakeholder types) was engaged in the scenario development process at what time (when) and with which method (how). Semi-structured interviews were conducted with 20 stakeholders ranging from non-governmental organizations (NGO) representatives, farmers and farm representatives, scientists, industry professionals and policy makers from across Europe. Three workshops were held with different spatial and stakeholder foci. Group discussions were held with livestock farmers and students in Austria. Finally, eight stakeholders participated in the peer and stakeholder review of the scenarios. Specific methods used in the scenario development process, as well as the timeline are summarized in figure 4. The individual methods are described in the respective working steps.

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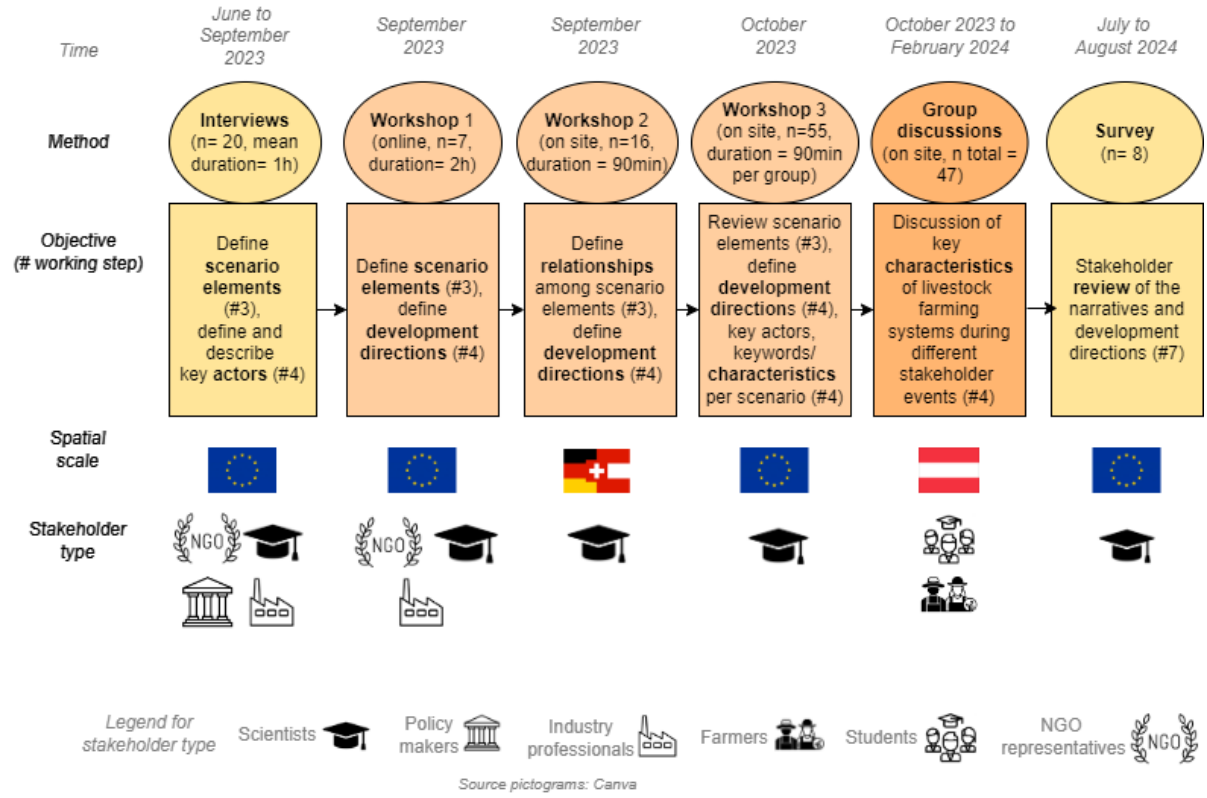


**Figure 3**: Overview of stakeholder engagement in the scenario development process.

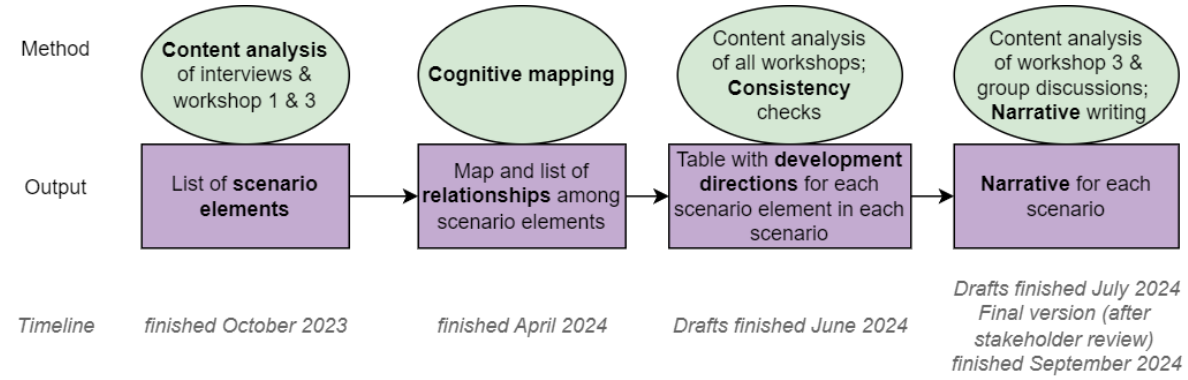


**Figure 4**: Overview of the methods used for scenario development.

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## 3.1. Define key characteristics

The key characteristics were defined according to the suggestions provided by Mitter et al. (2019) and include the scenario purpose, geographical and temporal extent, the target groups, and the type of scenarios. Furthermore, scenario quality criteria were specified in this working step.

## 3.2. Set-up stakeholder group

Stakeholders interested in and relevant for European livestock farming systems were identified through the project consortium, contacts made during developing the Eur-Agri-SSPs, online search, and snowball sampling. We aimed for a diverse stakeholder group in terms of three criteria: (i) type of organization, i.e., farmers and farm representatives, industry professionals, NGO representatives, policy makers, scientists, and students, (ii) gender, and (iii) country representation. While a list of stakeholders was collected, the stakeholder type to be invited or to work with was decided for each individual working step, depending on its aims (figure 3).

Where possible, the workshops and group discussions were held within different types of events – targeting different types of stakeholders. Workshop 1 was conducted on 18 September 2023 during an online event of the Multi-Actor Platform (MAP), which was established within the Re-Livestock project (WP1). The engaged stakeholders were industry professionals, NGO representatives, policy makers and scientists.

Workshop 2 was held during the annual conference of the Austrian Society of Agricultural Economics on 28 September 2023 in Vienna, Austria. The main target group was scientists as well as policy makers, NGO representatives and farmers and farm representatives from the DACH region (Austria, Germany and Switzerland) who typically attend the annual conference. The participants covered the topics “Economy” and “Policies & Institutions” as well as “Technology” and “Environment & Natural resources”.

Workshop 3 was conducted within the General Assembly of the Re-Livestock consortium in Frick, Switzerland on 25 October 2023. The target group was scientists and industry professionals working on livestock farming systems in Europe. Their thematic focus was on “Technology” and “Environment & natural resources” as well as “Economy”.

One group discussion was held during the event “Landwirtschaft trifft Uni” (Agriculture meets University) in Vienna, Austria on 24 October 2023. The target group was livestock farmers and students of agriculture from across Austria. The second and third group discussions were conducted with livestock farmers during the event “Alianza Lernbesuch Steiermark” (study visit Styria) in Ilztal, Austria on 15 February 2024 and in Trahütten, Austria on 16 March 2024.

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## 3.3. Define scenario elements

We aimed for a comprehensive set of scenario elements, while keeping its number as low as possible. Scenario elements were derived by content analysis of the semi-structured interviews and workshops, as shown in figure 4. All suggested scenario elements were grouped along the five topics of the Eur-Agri-SSPs: “Population & Urbanization”, “Economy”, “Policies & Institutions”, “Technology”, “Environment & Natural Resources” (Mitter et al., 2020). When possible, scenario elements were clustered to limit their number. If stakeholders suggested scenario elements similar to one of the Eur-Agri-SSP scenario elements, the Eur-Agri-SSP scenario element was taken. Furthermore, scenario elements of the Eur-Agri-SSPs were not duplicated. The list of scenario elements was revised after each stakeholder engagement activity and all changes were discussed in a group of researchers.

The final list of scenario elements as well as results of workshop 2 served as a basis for a system diagram which was derived using cognitive mapping (figure 4). The activity during workshop 2 that focused on the development of the system diagram consisted of four steps. First, the participants were asked to identify the most important drivers of changes in European livestock farming systems using the list of scenario elements. The participants could propose changes to the scenario elements or add missing ones. Second, the participants were asked to document causal relationships between the scenario elements they consider important. They were asked to draw an arrow if one scenario element influences another scenario element. In addition, they were asked to add a (+) sign for a positive, reinforcing relationship or a (-) sign for a negative relationship, depending on the direction of the effect of the relationship. For instance, if the increase of the scenario element A leads to a decline in the scenario element B, the scenario element A has a negative effect on B (-). Also, if a decline in the scenario element A leads to an increase in the scenario element B, the scenario element A has a negative effect on B (-). By contrast, if an increase of the scenario element A leads to an increase of the scenario element B, the scenario element A has a reinforcing, positive effect on B (+). Also, if a decline in the scenario element A leads to a decline in the scenario element B, the scenario element A has a positive, reinforcing effect on B (+). Third, the participants were asked to identify key actors who would shape the development of European livestock farming systems by 2050. Fourth, they were asked to identify the relationships between the identified actors and the key scenario elements.

The workshop transcripts and documents of workshop 2 were analysed. In particular, any relationship between the scenario elements mentioned by the participants was coded and used as input into the system diagram (figure 3). The identified relationships were categorized into causal, conditional, consecutive, concessive, final or restrictive (table 1) and coded accordingly. Causal relationships refer to reasons and their effects and can be answered through questions like “Why?” or “For what reason?”. Conditional relationships can be answered through questions like “When?” or “Under what conditions?”. Consecutive relationships relate to consequences resulting from previous action. Concessive relationships relate to unexpectedness. Final relationships relate to the purpose and can be answered through questions like “For what purpose?” or “With what intention?”. Restrictive relationships can be described as those where the scenario elements to some extent exclude or limit each other.

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The categories of the relationships were identified through signal words such as adverbs, conjunctions and prepositions articulated by the participants. Table 1 lists them in German, as workshop 2, where these relationships have been discussed, was held in German. Causal relationships were identified through signal words such as “because of”, “hence”, “therefore”, “as a result of”, “drive”. Signal words for identifying conditional relationships have been for instance “then”, “otherwise”, “by no means”, “if”, “in case of”. Consecutive relationships were identified through, e.g., “also”, “thus”, “as a consequence of”. Concessive relationships were identified through, e.g., “nonetheless”, “nevertheless”, “although”, “despite”, “yet”. Signal words of final relationships have been, for instance, “for this”, “so that”, “for the purpose of”. Restrictive relationships were identified, e.g., through “except that”. The derived relationships were cross-checked by two researchers.

**Table 1**: Category of relationships between scenario elements.

| Category of relationship | Description | Adverbs of the transcripts (in German) | Conjunctions of the transcripts (in German) | Prepositions of the transcripts (in German) |
|---|---|---|---|---|
| **Causal** | Reason, causal relationship in the narrow sense - Why? For what reason? | deshalb, deswegen, daher, aus diesem Grund | weil, da, denn, nämlich | wegen, aufgrund, infolge, aus, vor |
| **Conditional** | Condition - When? Under what conditions? | dann, andernfalls, ansonsten, keinesfalls, sonst | wenn, falls, sofern | bei, mit, durch, ohne, im Falle (von) |
| **Consecutive** | Consequence resulting from previous action | also, daher, darum, deshalb, deswegen, folglich, infolgedessen | sodass, so Adj., dass | infolge (von) |
| **Concessive** | Concession, acknowledging opposing views | dennoch, trotzdem, nichtsdestotrotz, dennoch, allerdings | obwohl, obgleich, zwar, … aber | trotz, ungeachtet |
| **Final** | Purpose, intention, aim - For what purpose? With what intention? | dazu, wozu, darum, deshalb, hierfür, dafür, hierzu | damit, um … zu | zwecks, zu, für |
| **Restrictive** | Restriction, constraint | außer… das | | |

Note: Examples for English adverbs, conjunctions and prepositions are given in the text.

The identified relationships defined the first draft of the system diagram, which represented large parts of the European livestock farming system. However, the researchers considered the derived system diagram as incomplete because no or only few causal relationships had been identified for several scenario elements during the workshops. For instance, no causal relationships had been identified for 30 scenario elements. A main reason for the limitations of

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the first draft of the system diagram were time constraints that the participants faced during the workshops. Hence, two researchers manually added relationships among scenario elements in the system diagram. This task was done within a matrix depicting the scenario elements and their relationships. The researchers also conducted a literature review collecting evidence on causal relationships in the livestock farming system in case of uncertainty. In addition, a third type of relationship was added besides positive (+) and negative (-): indifferent (0). Indifferent (0) was chosen if the direction of the effect is unclear or ambiguous, e.g., because it depends on a specific circumstance (i.e., the relationship is only positive or negative under a specific circumstance or under a specific development of a third scenario element) or because it depends on the size of the scenario element (i.e., scenario element A positively influences scenario element B only above a certain threshold). The identified relationships were cross-checked by the two researchers. As the resulting number of relationships was rather large, the two researchers reviewed potential indirect drivers and relationships, as exemplarily shown in figure 5. In figure 5, the scenario element A influences the scenario element B, as well as the scenario element C, according to the system diagram. The scenario element B also influences the scenario element C.

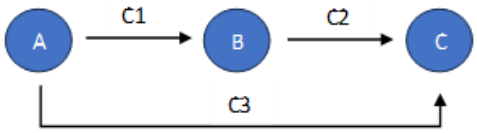


**Figure 5:** Example for identifying indirect drivers and relationships.

An indirect driver or relationship was identified according to four rules:

1) If driver B could be defined as a “special case” of driver A, the special case driver was excluded because the causality is already covered (e.g., driver B “Occurrence of communicable diseases” can be interpreted as a “special case” of driver A “Animal health”, both identified as drivers of driver C “Animal welfare awareness”).
2) If driver B could be classified as an indirect driver, only the direct driver A was kept (e.g., driver A “Animal welfare awareness” was classified as a direct driver and driver B “Per capita demand for animal welfare products” was classified as an indirect driver of driver C “Animal welfare standards”).
3) If a driver causality turned out to be necessary in the scenario context, all driver causalities were kept (e.g., driver A “Carbon price” and driver B “Variable costs of livestock production” were classified as necessary drivers of driver C “Relative prices of animal-based food products” and hence all relationships were kept).
4) Causalities raised during the workshop were given priority, compared to researcher-added causalities, in case of uncertainty.

The final system diagram shows which scenario elements influence a particular scenario element. It served the purpose of deriving consistent development directions for the scenario elements in each Eur-LFS-SSP, which was ensured via the consistency check (working step 5).

Finally, the development directions for each scenario element were specified in each scenario (Figure 4). Five development directions were distinguished: moderate or strong increase,

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moderate or strong decrease or constant development. The development directions always referred to the status quo of the scenario element in 2023.

The first version of the development directions was specified according to the “majority view” of workshops 2 and 3, which was achieved as follows. In both workshops, participants were asked to define a development direction of a scenario element in a particular Eur-LFS-SSP individually, without any discussion with other participants. For this purpose, a sub-set of scenario elements was handed to each participant. Participants were asked to specify the development directions of these scenario elements for all five Eur-LFS-SSPs. In workshop 3, participants were additionally asked to discuss the development directions with other participants to reach a group decision on the development direction. All individual and group decisions were documented. From these, each development direction was counted for each respective scenario element and Eur-LFS-SSP. The development direction with the highest count was specified for the respective scenario as a first version. These development directions were then subject to the consistency check (working step 5) and, later, to the stakeholder and peer review (working step 7) to obtain the final version. The development directions of few scenario elements were not discussed in any of the workshops for two reasons. Some scenario elements were specified during the last workshop and, hence, were not planned to be discussed in detail. Other scenario elements were on the list to be discussed during the workshops but the participants did not take them up, presumably because of limited interest or expertise. For the scenario elements that were not discussed in any of the workshops, the first version of the development direction was based on the development direction specified for the drivers of the respective scenario element in the system diagram.

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## 3.4. Draft narratives

The following requirements were placed on the narratives, besides meeting the quality criteria specified in Mitter et al. (2019):

- Length: 1.5-2 pages.
- Structure: following the five topics: “Population & urbanization”, “Economy”, “Policies & Institutions”, “Technology”, “Environment & Natural Resources”.
- Appropriate heading and sub-heading for each topic.
- A short summary of each narrative at the end that refers to challenges to climate change mitigation and challenges to climate change adaptation.

The final list of scenario elements with their respective development directions (i.e., after the consistency check) served as a basis for writing drafts of the narratives. Furthermore, the key characteristics, actors and innovations mentioned in workshop 3 and the group discussions served as input. To derive a very first draft of the narratives the AI chatbot ChatGPT-4o was used. The following prompt was used: “Please prepare one narrative text of about 1.5 pages focusing on the topics "population and urbanization", "policies and institutions", "economy", "technology" and "environment and natural resources" using the information in the attached file. Include informative sub headings for the five topics. And suggest an appropriate title for this narrative.”. A document with the table of the development directions and the excerpts of the workshop transcripts (regarding key actors, innovations and characteristics) for the respective Eur-LFS-SSP was attached to the prompt. The resulting draft narratives were carefully checked by two researchers with respect to the correct description of all development directions, correct names of the scenario elements, coherent and consistent relationships and reasoning of the developments of the scenario elements, and clear wording. Any normative aspects, if present, were excluded from the narrative. In particular, the revision required in particular the inclusion of concrete examples for the livestock farming systems and the description of the relationship among scenario elements based on the system diagram. The revised narratives were then subject to peer and stakeholder review (working step 7).

## 3.5. Consistency checks

The consistency check focused on three types of consistency:

- Internal consistency of the Eur-LFS-SSPs: Are the developments of one Eur-LFS-SSP consistent in itself?
- Horizontal consistency of the Eur-LFS-SSPs: Are the developments of one Eur-LFS-SSP consistent and contrasting enough with the developments of the other four Eur-LFS-SSPs?
- Vertical Consistency with the Eur-Agri-SSPs: Are the developments of one Eur-LFS-SSP consistent with the developments of the respective Eur-Agri-SSP?

Internal consistency was evaluated by translating the development directions and the direction of effect of the relationship between scenario elements, according to the system diagram, and the numbers shown in table 2.

**Table 2**: Overview of the assigned numbers representing the development directions as well as the direction of effect of the relationships between scenario elements.

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| Development direction | Direction of effect of the relationship | Number |
|---|---|---|
| Strong decrease | N.A. | -2 |
| Moderate decrease | Negative | -1 |
| Constant | Indifferent | 0 |
| Moderate increase | Positive / Reinforcing | +1 |
| Strong increase | N.A. | +2 |

For each scenario element *i* a consistency value *x* was calculated using equation (1), whereby *d* refers to development directions, and *e* refers to the direction of effect of the relationships with scenario element j. The sum of all defined relationships *J* varied from one to ten, which was the maximum number of relationships defined by the stakeholders or involved researchers. This maximum number was not limited in order to depict a comprehensive system diagram. A value of $x \geq 1.5$ indicates that at least half of the scenario elements that influence the scenario element *i* had a strong development direction. Hence, if *x* was equal to or larger than 1.5 and/or if the scenario logic allows, a strong development direction was chosen (i.e., strong increase or strong decrease). However, this calculation only served as an orientation and allowed a fast review of changes if the development direction of a single scenario element was changed. The main reason for specifying a strong development was the scenario logic and the stakeholder comments together with the calculated consistency value.

$$x_i = \frac{\sum_j d_{i,j} * e_{i,j}}{J} \qquad (1)$$

After one round of such an internal consistency check, the horizontal consistency was examined. The focus of the horizontal consistency was to ensure that the development directions of the scenario elements are contrasting between the individual Eur-LFS-SSPs, according to the scenario logic. For instance, scenario elements from the topic “Environment & Natural Resources” can be expected to be different, in particular in Eur-LFS-SSP1 and Eur-LFS-SSP3. For this purpose, the development direction of one scenario element was compared across the five Eur-LFS-SSPs. The scenario logic was used to evaluate in which Eur-LFS-SSP a stronger development is plausible, compared to the others or to identify any conflicts. For instance, a strong increase in environmental standards in Eur-LFS-SSP5 compared to a medium increase in Eur-LFS-SSP1 would be against the scenario logic.

The vertical consistency check followed the horizontal consistency check. For this purpose, scenario elements of the Eur-Agri-SSPs were mapped to similar scenario elements of the Eur-LFS-SSPs. Then, the development direction of each mapped scenario element was compared between all five Eur-Agri-SSPs and Eur-LFS-SSPs.

Each consistency check led to some changes in the development directions of some scenario elements. Therefore, four rounds of consistency checks (i.e., comprising of internal, horizontal and vertical consistency checks) were conducted until no further changes were obtained.

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## 3.6. Develop presentation formats

This working step comprised of illustrating major differences and commonalities between the narratives, and defining a meaningful scenario title. The researchers suggested short conclusions for each Eur-LFS-SSP which summarize arising challenges for climate change mitigation and climate change adaptation. They also proposed acronyms for the scenarios. Sub-titles and titles for each Eur-LFS-SSP were first AI-generated. The researchers revised these first version such that all sub-titles and titles follow a similar structure, are adequate for each topic and Eur-LFS-SSP and are contrasting enough between the Eur-LFS-SSPs. The acronyms, conclusions, sub-titles and titles were part of the peer and stakeholder review as described next (working step 7).

## 3.7. Peer and stakeholder review

The partners of the Re-Livestock consortium were invited to register as a reviewer for the narratives and the table presenting the development directions of the scenario elements. In total, 10 persons volunteered for the review process. A minimum of two Eur-LFS-SSPs were assigned to each volunteer. One person volunteered to review three Eur-LFS-SSPs, one four and one all five. On average, 5 to 6 reviewers were assigned to each Eur-LFS-SSP. A questionnaire, shown in the appendix, was prepared which had to be answered by each reviewer for each assigned Eur-LFS-SSP. The questionnaire was based on the quality criteria which should be met by the scenarios. A brief introduction and explanation of key terms (i.e., glossary) was provided prior to the questionnaire. The reviewers were also invited to comment narrative texts and the development directions presented in the table.

## 3.8. Dissemination

Dissemination formats and channels have been defined in this working step. The Eur-LFS-SSPs and the scenario development process are planned to be published as a peer-reviewed article in a scientific journal. Furthermore, the Eur-LFS-SSPs will be shared among all stakeholders who contributed to the scenarios, the Re-Livestock consortium and the GreeNet consortium. GreeNet (greenet.boku.ac.at) is a 2021-2022 Biodiversa+ funded research project interested in applying the Eur-LFS-SSPs. Finally, the Eur-LFS-SSPs are planned to be presented at scientific conferences and at stakeholder workshops.

## 3.9. Evaluate collaboration

The participants of the workshops were asked for feedback in the end of the respective events. An online survey or a flipchart was used to derived feedback on the following statements using either a four-point rating scale (strongly agree, agree, disagree or strongly disagree) or an axis ranging from strongly disagree to strongly agree:

- My expectations of the workshop were met.
- The workshop content and tasks were clearly explained. *(not asked in workshop 2)*
- The workshop presentations and discussions are of relevance for my daily work.

In addition, participants of the peer and stakeholder review were asked about the usefulness of the Eur-LFS-SSPs for their daily work (see evaluation questions in working step 7).

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# 4. Results

## 4.1. Key characteristics

The purpose of the Eur-LFS-SSPs is to develop a set of five scenarios for the European livestock farming systems, which extend the Eur-Agri-SSPs in a consistent way. Accordingly, the geographical extent is Europe, whereby a further specification of Europe (e.g., geographic or administrative) is consciously avoided. The time horizon is aligned to the Eur-Agri-SSPs and, hence, set to 2050. The target groups of the Eur-LFS-SSPs are decision-makers and scientists working on livestock farming systems. The type of scenarios are qualitative narratives as well as semi-quantitative development directions for the scenario elements. The scenario quality criteria have been defined for the Eur-Agri-SSPs (Mitter et al., 2019) and the AT-Agri-SSPs (Karner et al., 2024) and are also followed for the Eur-LFS-SSPs: the final scenarios shall be plausible, easy to comprehend, rich in detail, legitimate, consistent, creative and shall adequately account for the specifics of European livestock farming systems.

## 4.2. Stakeholder group

Table 3 shows the stakeholders who have been engaged in the scenario development process, categorized by gender an organization type they represent. In total, 153 stakeholders from across Europe have been engaged during the scenario development process. They have been engaged either via semi-structured interviews (n=20), by participating in one of the three workshops 1-3 (n=78), by participating in one of the group discussions (n=47) or by contributing to the peer and stakeholder review (n=8). Table 4 presents the stakeholders organized by the country cluster of their respective affiliations. At the time of their participation, the majority of the stakeholders was active in science, followed by students (who participated in the group discussions), farmers and farm representatives (who mainly participated in the group discussions), NGO representatives, and industry professionals. 42% of the engaged stakeholders are female. With respect to countries and regions, organizations located in Eastern Europe or active across Europe are less represented than organizations operating in Western Europe or Mediterranean countries. The DACH region is disproportionally well represented because students and farmers participating in the group discussions were mainly from Austria. In the semi-structured interviews and the workshops, 26 stakeholders from the DACH region participated, hence, slightly fewer than from Western Europe (27) or Mediterranean countries (30).

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**Table 3:** Overview of the number of engaged stakeholders presented by organization type and gender.

| Organization type | Female | Male | No answer | Total |
|---|---|---|---|---|
| **Farmers and farm representatives** | 8 | 11 | 0 | 19 |
| **Industry professionals** | 6 | 6 | 0 | 12 |
| **NGO representatives** | 9 | 6 | 0 | 15 |
| **Policy makers** | 0 | 3 | 0 | 3 |
| **Scientists** | 29 | 47 | 0 | 76 |
| **Students** | 12 | 15 | 1 | 28 |
| ***Total*** | ***64*** | ***88*** | ***1*** | ***153*** |

**Table 4**: Overview of the number of engaged stakeholders presented by a clustered country representation of the stakeholder organizations.

| Clustered country representation of stakeholder organizations | Total |
|---|---|
| **DACH** | 73 |
| **DK / IE / NL / UK / SE** | 30 |
| **ES / FR / IT / PT** | 34 |
| **PL / SL / UKR** | 9 |
| **Europe** | 7 |
| ***Total*** | ***153*** |

Notes: DACH = Germany, Austria, Switzerland; DK = Denmark, IE = Ireland, NL = Netherland, UK = United Kingdom, SE = Sweden; ES = Spain, FR = France, IT = Italy, PT = Portugal; PL = Poland, SL = Slovenia, UKR = Ukraine

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## 4.3. List of scenario elements informing the system diagram

Table 5 shows the full list of scenario elements derived from the stakeholder engagement process, that have been considered for deriving the system diagram. Most scenario elements are part of the topic “Economy” (n= 30), followed by “Policies & Institutions” (n= 19), “Technology” (n=15), “Population & Urbanization” (n=12), and “Environmental & Natural Resources” (n=6). In total, 83 scenario elements were identified as drivers of changes in European livestock farming systems. Thereof, 15 scenario elements were taken from the Eur-Agri-SSPs because the drivers suggested by the stakeholders were very similar. These scenario elements are marked in table 5. The full list of scenario elements (table 5) was slightly revised after the peer and stakeholder review and internal discussions of the researchers. In particular, three scenario elements (i.e. “Competition in farming”, “Occurrence of protest movements for sustainable transformation of livestock farming systems”, and “Per capita demand for clean milk”) were excluded from the list given the aim to avoid duplications and very similar or vague scenario elements. Thereby, the total number of scenario elements was reduced, which also reduced system complexity and increased readability of the narratives. In the end, 80 scenario elements remained, whereby 65 are additional to the scenario elements of the Eur-Agri-SSPs.

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**Table 5: List of scenario elements informing the system diagram**

| ID | Topic | Scenario element |
|---|---|---|
| 1 | Economy | Average income of agricultural labour |
| 2 | | Average income of citizens |
| 3 | | Average income of farmers |
| 4 | | Competition in farming |
| 5 | | Demand for biogenic resources for biogas production |
| 6 | | Eur-Agri-SSPs: Diversity of agricultural supply chains |
| 7 | | Eur-Agri-SSPs: Labour supply in agriculture |
| 8 | | Eur-Agri-SSPs: Land productivity |
| 9 | | Eur-Agri-SSPs: Market integration |
| 10 | | Eur-Agri-SSPs: Pace of structural change in agriculture |
| 11 | | European export of animal-based food products |
| 12 | | European export of animal feed |
| 13 | | European import of animal-based food products |
| 14 | | European import of animal feed |
| 15 | | Fixed costs of livestock production |
| 16 | | Income equality |
| 17 | | Per capita demand for animal welfare products |
| 18 | | Per capita demand for clean milk |
| 19 | | Per capita demand for cultured animal-based food products |
| 20 | | Per capita demand for processed meat and milk substitutes |
| 21 | | Per capita demand for plant-based food products |
| 22 | | Per capita demand for conventional animal-based food products |
| 23 | | Private investment volume in animal welfare |
| 24 | | Public investment volume in animal welfare |
| 25 | | Regional manure trading system |
| 26 | | Relative prices of animal-based food products |
| 27 | | Relative prices of livestock breeding technology |
| 28 | | Relative prices of synthetic fertilizers |
| 29 | | Variable costs of livestock production |
| 30 | | Working conditions of farmers and agricultural labour |
| 31 | Environment & Natural resources | Animal health |
| 32 | | Availability and quality of organic fertilizers |
| 33 | | Availability of agricultural land |
| 34 | | Biodiversity (genetic, species and ecosystem diversity) |
| 35 | | Global land availability for animal nutrition and husbandry |
| 36 | | Occurrence of communicable zoonotic diseases |
| 37 | | Share of agricultural land with cultivation restrictions resulting from nature protection |
| 38 | Policies & Institutions | Accessibility of agricultural extension services (public or private) |
| 39 | | Animal welfare standards |
| 40 | | Carbon budget for livestock farming systems |
| 41 | | Carbon credits in agriculture |
| 42 | | Carbon price |
| 43 | | Eur-Agri-SSPs: Environmental standards |
| 44 | | Eur-Agri-SSPs: Food standards |
| 45 | | Eur-Agri-SSPs: International trade agreements |
| 46 | | Eur-Agri-SSPs: Multilevel cooperation |
| 47 | | Eur-Agri-SSPs: Socio-environmental focus of agri-food policies |
| 48 | | International standards for carbon sequestration |

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| | | |
|---|---|---|
| 49 | | Knowledge exchange between actors in livestock farming systems |
| 50 | | Land use regulation to prioritize plant-based food production |
| 51 | | Political attention for climate change mitigation and adaptation in livestock farming systems |
| 52 | | Political attention for internalizing external costs of livestock farming systems |
| 53 | | Public investment volume in education and food literacy |
| 54 | | Regional collaborations between farmers |
| 55 | | Taxes for non-CO2 GHG emissions driven by livestock farming systems |
| 56 | | Traceability standards for agricultural commodities |
| 57 | Population & Urbanization | Animal welfare awareness of citizens |
| 58 | | Appreciation of agricultural work by consumers |
| 59 | | Attractiveness of circular farming for farmers and citizens |
| 60 | | Consumers' attention to ecolabels |
| 61 | | Eur-Agri-SSPs: Environmental awareness of citizens |
| 62 | | Eur-Agri-SSPs: Urban-rural linkages |
| 63 | | Farmers' intrinsic motivation for farming |
| 64 | | Farmers' technology expertise |
| 65 | | Food literacy of consumers |
| 66 | | Living standards of farmers and agricultural labour |
| 67 | | Occurrence of protest movements for sustainable transformation of livestock farming systems |
| 68 | | Societal pressure for sustainable livestock farming systems |
| 69 | Technology | Animal feed efficiency |
| 70 | | Climate adaptive breeding |
| 71 | | Degree of automatization in livestock farming systems |
| 72 | | Degree of digitalization in livestock farming systems |
| 73 | | Eur-Agri-SSPs: Speed of agricultural technology development |
| 74 | | Eur-Agri-SSPs: Technology acceptance by producers and consumers |
| 75 | | Eur-Agri-SSPs: Technology uptake in agriculture |
| 76 | | Interoperability of technologies |
| 77 | | Manure management efficiency |
| 78 | | Speed of certification and accreditation of new technologies |
| 79 | | Speed of technology development for plant-based food products |
| 80 | | Use of climate-friendly technologies for fertilizer application |
| 81 | | Use of fossil-fuel based machinery |
| 82 | | Use of technologies for animal health |
| 83 | | Use of technologies for greenhouse gas emission monitoring |

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## 4.4. System diagram

A system diagram was developed to visualize the scenario elements, their causal relationships and the directions of influence, whereby the scenario elements were presented as nodes and the causal relationships as edges (Figure 6). The major purpose of the system diagram is to structure the European livestock farming system and its potential future behaviour by focusing on a manageable number of scenario elements. In addition, the system diagram formed the basis for drafting narratives and checking the consistency of the narratives. In total, the system diagram includes 349 causal relationships, i.e. edges. Most edges are positive. Hence, most scenario elements have a positive, reinforcing relationship with the scenario elements they influence. In particular, out of the 349 identified relationships, 255 are positive, 76 are negative, and 18 are described as indifferent.

A system diagram can be characterized by the number of in-degrees and the number of out-degrees of its elements (i.e., drivers). The in-degree of a specific scenario element reflects the count of other scenario elements that exert influence on it. Hence, it serves as an indicator of the number of links or connections that a node has to other nodes through incoming edges. By contrast, the out-degree of a specific scenario element reflects the count of other scenario elements that exert influence on it. Hence, it serves as an indicator of the number of links or connections that a node has to other nodes through outgoing edges (Borgatti et al., 2013).

Table 6 shows the scenario elements with the highest number of in-degrees. “Variable cost of livestock production” is influenced by 11 other scenario elements, which makes it the scenario element with the highest number of in-degrees. It is followed by “Relative prices of animal-based food products”, “Per capita demand for plant-based food products”, and “Carbon budget for livestock farming systems”. All four scenario elements shown in table 6 are part of the topic “Economy”. Figure 6 visualizes the system diagram, whereby a higher number of in-degree is reflected by a larger size of the scenario element. The numbers in figure 6 relate to the IDs of the scenario elements, as listed in table 5. The colour refers to one of the five topics, as shown in table 5.

**Table 6:** The scenario elements with more than six in-degrees.

| ID | Scenario element | In-degree |
|---|---|---|
| 29 | Variable cost of livestock production | 11 |
| 26 | Relative prices of animal-based food products | 10 |
| 22 | Per capita demand for plant-based food products | 8 |
| 40 | Carbon budget for livestock farming systems | 7 |

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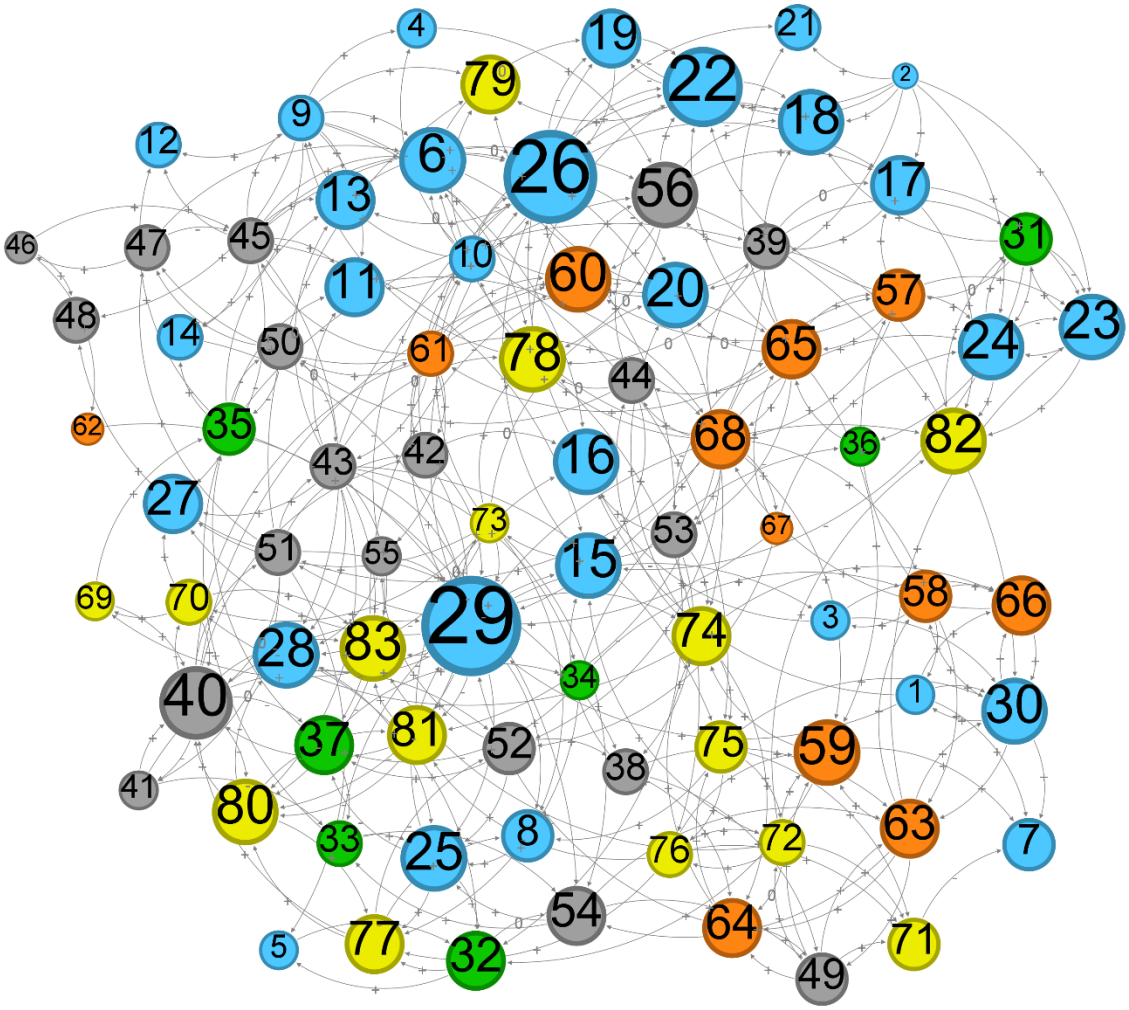


**Figure 6:** System diagram of the European livestock farming system showing the in-degrees.

Note: The number refers to the ID of the scenario element as shown in table 5, the colour refers to the topic to which the scenario element belongs to (see table 5) and the size reflects the count of in-degrees of the respective scenario element.

Table 7 lists the five scenario elements with the highest number of out-degrees. These scenario elements influence most other scenario elements and, therefore, represent the most influential scenario elements. Interestingly, “Variable cost of livestock production” is not only the scenario element with the highest number of in-degrees, but also the one with the highest number of out-degrees. The scenario elements “Societal pressure for sustainable livestock farming system” and “Environmental awareness of citizens” belong to the topic “Population & Urbanization, and the scenario elements “Environmental standards” and “International trade agreements” belong to the topic “Policies & Institutions”. Figure 7 depicts the system diagram, whereby a higher number of out-degrees is reflected by a larger size of the scenario element.

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**Table 7:** The scenario elements with more than six out-degrees.

| ID | Scenario element | Out-degree |
|---|---|---|
| 29 | Variable cost of livestock production | 14 |
| 68 | Societal pressure for sustainable livestock farming system | 13 |
| 43 | Eur-Agri-SSPs: Environmental standards | 12 |
| 45 | Eur-Agri-SSPs: International trade agreements | 11 |
| 61 | Eur-Agri-SSPs: Environmental awareness of citizens | 11 |

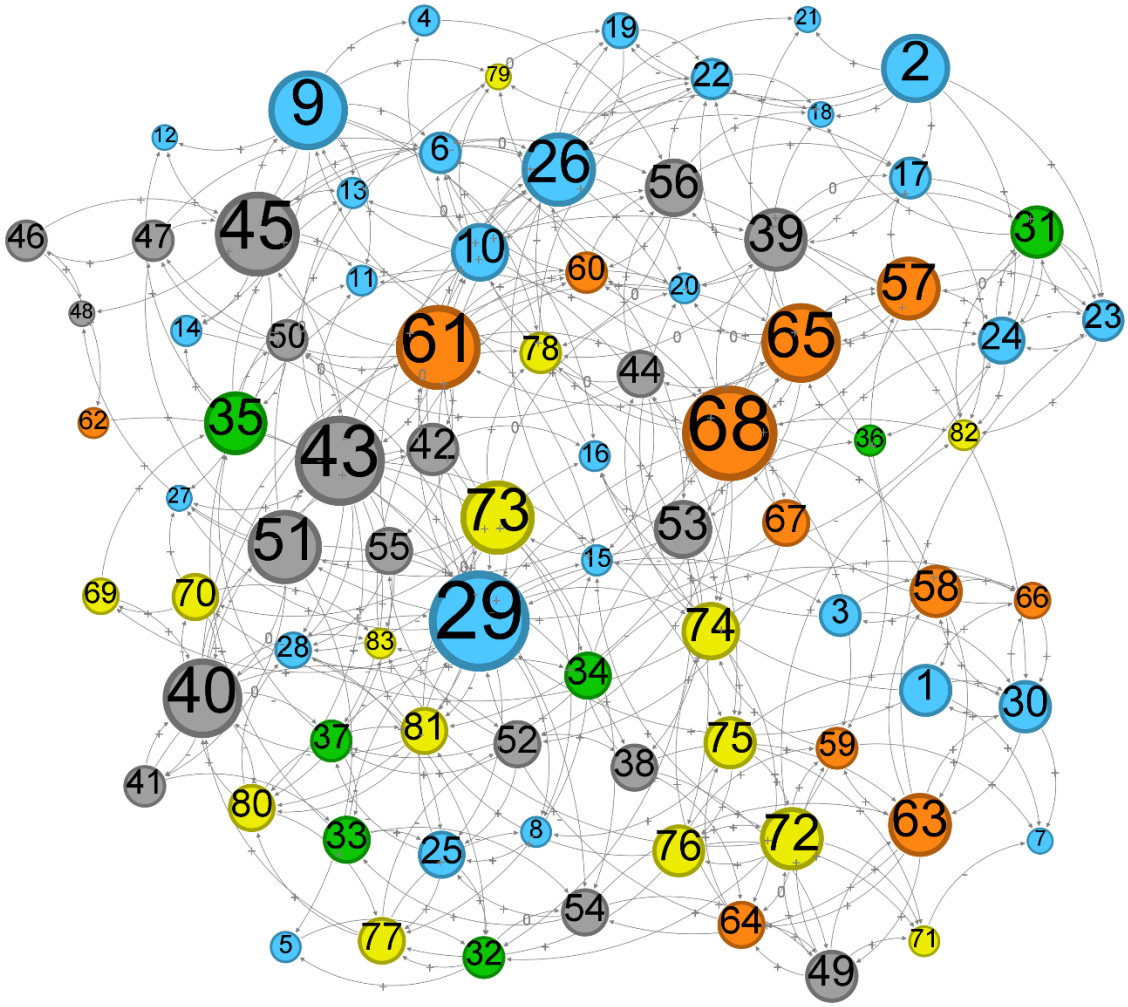


**Figure 7:** System diagram of the European livestock farming system showing the out-degrees.

Note: The number refers to the ID of the scenario element as shown in table 5, the colour refers to the topic to which the scenario element belongs to (see table 5) and the size reflects the count of out-degrees of the respective scenario element.

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## 4.5. Development directions of the scenario elements

Table 8 shows how the scenario elements develop in each of the five Eur-LFS-SSPs. The IDs and the colour code of the topics match the ones presented in table 5. The development directions are colour coded as well to increase readability of the differences among development directions. Blue refers to a moderate or strong decrease of the scenario element, red refers to a moderate or strong increase of the scenario element, and yellow shows a constant development, i.e., no change compared to the current situation. The extent (medium, strong) is coded via the shade of the colour.

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**Table 8:** Development directions of the scenario elements in the five Eur-LFS-SSPs. Five development directions are distinguished: strong increase (2, ↑, dark red shade), moderate increase (1, ↗, light red shade), constant development (0, →, yellow shade), moderate decrease (-1, ↘, light blue shade) and strong decrease (-2, ↓, dark blue shade). The IDs refer to those in table 5.

| Topic | ID | Scenario element | Development Eur-LFS-SSP1 | Development Eur-LFS-SSP2 | Development Eur-LFS-SSP3 | Development Eur-LFS-SSP4 | Development Eur-LFS-SSP5 |
|---|---|---|---|---|---|---|---|
| Population & Urbanisation | 57 | Animal welfare awareness of citizens | ↑ 2 | ↗ 1 | ↘ -1 | ↘ -1 | ↘ -1 |
| | 58 | Appreciation of agricultural work by consumers | ↗ 1 | → 0 | ↗ 1 | ↘ -1 | → 0 |
| | 59 | Attractiveness of circular farming for farmers and citizens | ↑ 2 | ↗ 1 | → 0 | ↗ 1 | ↓ -2 |
| | 60 | Consumers' attention to ecolabels | ↑ 2 | ↗ 1 | ↓ -2 | ↘ -1 | ↓ -2 |
| | 61 | Eur-Agri-SSPs: Environmental awareness of citizens | ↑ 2 | ↗ 1 | ↘ -1 | ↘ -1 | ↓ -2 |
| | 62 | Eur-Agri-SSPs: Urban-rural linkages | ↗ 1 | → 0 | ↘ -1 | ↘ -1 | ↘ -1 |
| | 63 | Farmers intrinsic motivation for farming | ↗ 1 | ↘ -1 | → 0 | ↘ -1 | ↗ 1 |
| | 64 | Farmers' technology expertise | ↗ 1 | ↗ 1 | ↘ -1 | ↗ 1 | ↑ 2 |
| | 65 | Food literacy of consumers | ↑ 2 | ↗ 1 | → 0 | ↘ -1 | → 0 |
| | 66 | Living standards of farmers and agricultural labour | ↗ 1 | → 0 | ↘ -1 | → 0 | ↗ 1 |
| | 68 | Societal pressure for sustainable livestock farming systems | → 0 | ↗ 1 | ↓ -2 | ↘ -1 | ↓ -2 |
| Economy | 1 | Average income of agricultural labour | ↗ 1 | → 0 | ↘ -1 | ↘ -1 | ↗ 1 |
| | 2 | Average income of citizens | ↗ 1 | ↗ 1 | ↘ -1 | → 0 | ↑ 2 |
| | 3 | Average income of farmers | ↗ 1 | → 0 | ↘ -1 | ↗ 1 | ↗ 1 |
| | 5 | Demand for biogenic resources for biogas production | → 0 | ↗ 1 | ↗ 1 | → 0 | ↘ -1 |
| | 6 | Eur-Agri-SSPs: Diversity of agricultural supply chains | ↗ 1 | ↘ -1 | ↓ -2 | ↘ -1 | ↘ -1 |
| | 7 | Eur-Agri-SSPs: Labour supply in agriculture | → 0 | → 0 | ↘ -1 | → 0 | ↗ 1 |
| | 8 | Eur-Agri-SSPs: Land productivity | ↗ 1 | → 0 | → 0 | ↗ 1 | ↗ 1 |
| | 9 | Eur-Agri-SSPs: Market integration | → 0 | ↗ 1 | ↓ -2 | ↗ 1 | ↑ 2 |
| | 10 | Eur-Agri-SSPs: Pace of structural change in agriculture | → 0 | ↗ 1 | → 0 | ↗ 1 | ↗ 1 |
| | 11 | European export of animal-based food products | ↓ 2 | → 0 | ↓ -2 | ↗ 1 | ↗ 1 |
| | 12 | European export of animal feed | ↘ -1 | → 0 | ↓ -2 | → 0 | ↗ 1 |
| | 13 | European import of animal-based food products | ↘ -1 | → 0 | ↓ -2 | ↗ 1 | ↗ 1 |
| | 14 | European import of animal feed | ↓ -2 | → 0 | ↓ -2 | ↗ 1 | ↑ 2 |

**Table 8 continued**

| Topic | ID | Scenario element | Development Eur-LFS-SSP1 | Development Eur-LFS-SSP2 | Development Eur-LFS-SSP3 | Development Eur-LFS-SSP4 | Development Eur-LFS-SSP5 |
|---|---|---|---|---|---|---|---|
| | 15 | Fixed costs of livestock production | ↗ 1 | ↗ 1 | → 0 | ↗ 1 | ↘ -1 |
| | 16 | Income equality | ↗ 1 | → 0 | → 0 | ↓ -2 | → 0 |
| | 17 | Per capita demand for animal welfare products | ↑ 2 | ↗ 1 | ↓ -2 | ↘ -1 | ↘ -1 |
| | 19 | Per capita demand for conventional animal-based food products | ↓ -2 | ↘ -1 | → 0 | → 0 | → 0 |
| | 20 | Per capita demand for cultured animal-based food products | ↗ 1 | ↗ 1 | ↘ -1 | → 0 | ↑ 2 |
| | 21 | Per capita demand for processed meat and milk substitutes | → 0 | ↗ 1 | ↘ -1 | → 0 | ↑ 2 |
| | 22 | Per capita demand for plant-based food products | ↑ 2 | ↗ 1 | → 0 | → 0 | → 0 |
| | 23 | Private investment volume in animal welfare | ↗ 1 | → 0 | ↓ -2 | ↓ -2 | ↘ -1 |
| | 25 | Regional manure trading system | ↗ 1 | → 0 | ↗ 1 | → 0 | ↘ -1 |
| | 26 | Relative prices of animal-based food products | ↑ 2 | ↗ 1 | ↗ 1 | ↗ 1 | ↘ -1 |
| | 27 | Relative prices of livestock breeding technology | → 0 | ↘ -1 | ↗ 1 | → 0 | ↓ -2 |
| | 28 | Relative prices of synthetic fertilizers | ↑ 2 | ↗ 1 | ↑ 2 | ↑ 2 | ↓ -2 |
| | 29 | Variable costs of livestock production | → 0 | ↗ 1 | ↗ 1 | ↗ 1 | ↓ -2 |
| | 30 | Working conditions of farmers and agricultural labour | ↗ 1 | → 0 | ↘ -1 | → 0 | ↗ 1 |
| Policies & Institutions | 38 | Accessibility of agricultural extension services (public or private) | ↑ 2 | ↗ 1 | → 0 | ↘ -1 | ↘ -1 |
| | 39 | Animal welfare standards | ↑ 2 | ↗ 1 | ↘ -1 | ↘ -1 | ↘ -1 |
| | 40 | Carbon budget for livestock farming systems | ↓ -2 | ↘ -1 | ↑ 2 | ↘ -1 | ↑ 2 |
| | 41 | Carbon credits in agriculture | ↑ 2 | ↗ 1 | ↘ -1 | ↗ 1 | ↓ -2 |
| | 42 | Carbon price | ↑ 2 | ↗ 1 | ↓ -2 | ↗ 1 | ↓ -2 |
| | 43 | Eur-Agri-SSPs: Environmental standards | ↑ 2 | ↗ 1 | ↘ -1 | ↘ -1 | ↓ -2 |
| | 44 | Eur-Agri-SSPs: Food standards | ↑ 2 | ↗ 1 | → 0 | → 0 | ↗ 1 |

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**Table 8 continued**

| Topic | ID | Scenario element | Development Eur-LFS-SSP1 | Development Eur-LFS-SSP2 | Development Eur-LFS-SSP3 | Development Eur-LFS-SSP4 | Development Eur-LFS-SSP5 |
|---|---|---|---|---|---|---|---|
| | 45 | Eur-Agri-SSPs: International trade agreements | ↗ 1 | ↗ 1 | ↓ -2 | ↑ 2 | ↑ 2 |
| | 46 | Eur-Agri-SSPs: Multilevel cooperation | ↑ 2 | → 0 | ↓ -2 | ↗ 1 | ↗ 1 |
| | 47 | Eur-Agri-SSPs: Socio-environmental focus of agri-food policies | ↑ 2 | ↗ 1 | ↘ -1 | → 0 | → 0 |
| | 48 | International standards for carbon sequestration | ↑ 2 | ↗ 1 | ↓ -2 | → 0 | ↓ -2 |
| | 49 | Knowledge exchange between actors in livestock farming systems | ↑ 2 | → 0 | ↘ -1 | ↗ 1 | → 0 |
| | 50 | Land use regulation to prioritize plant-based food production | ↑ 2 | ↗ 1 | → 0 | ↘ -1 | ↓ -2 |
| | 51 | Political attention for climate change mitigation and adaptation in livestock farming systems | ↑ 2 | ↗ 1 | ↓ -2 | → 0 | ↘ -1 |
| | 52 | Political attention for internalizing external costs of livestock farming systems | ↑ 2 | ↗ 1 | ↓ -2 | → 0 | ↓ -2 |
| | 24 | Public investment volume in animal welfare | ↗ 1 | ↗ 1 | ↘ -1 | ↘ -1 | ↓ -2 |
| | 53 | Public investment volume in education and food literacy | ↑ 2 | ↗ 1 | ↘ -1 | ↘ -1 | → 0 |
| | 54 | Regional collaborations between farmers | ↗ 1 | → 0 | ↗ 1 | ↘ -1 | ↘ -1 |
| | 55 | Taxes for non-CO2 GHG emissions driven by livestock farming systems | ↑ 2 | ↗ 1 | ↓ -2 | ↗ 1 | ↓ -2 |
| | 56 | Traceability standards for agricultural commodities | ↑ 2 | ↗ 1 | ↓ -2 | → 0 | ↘ -1 |
| Technology | 69 | Animal feed efficiency | ↗ 1 | ↗ 1 | ↘ -1 | ↑ 2 | ↑ 2 |
| | 70 | Climate adaptive breeding | ↑ 2 | ↗ 1 | ↓ -2 | → 0 | ↑ 2 |
| | 71 | Degree of automatization in livestock farming systems | ↗ 1 | ↗ 1 | → 0 | ↑ 2 | ↑ 2 |
| | 72 | Degree of digitalization of livestock farming systems | ↑ 2 | ↑ 2 | → 0 | ↑ 2 | ↑ 2 |
| | 73 | Eur-Agri-SSPs: Speed of agricultural technology development | ↑ 2 | → 0 | ↘ -1 | ↗ 1 | ↑ 2 |
| | 74 | Eur-Agri-SSPs: Technology acceptance by producers and consumers | ↑ 2 | ↗ 1 | ↘ -1 | → 0 | ↑ 2 |
| | 75 | Eur-Agri-SSPs: Technology uptake in agriculture | ↑ 2 | ↗ 1 | ↘ -1 | ↗ 1 | ↑ 2 |

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**Table 8 continued**

| Topic | ID | Scenario element | Development Eur-LFS-SSP1 | Development Eur-LFS-SSP2 | Development Eur-LFS-SSP3 | Development Eur-LFS-SSP4 | Development Eur-LFS-SSP5 |
|---|---|---|---|---|---|---|---|
| | 76 | Interoperability of technologies | ↗ 1 | ↗ 1 | ↓ -2 | ↑ 2 | ↑ 2 |
| | 77 | Manure management efficiency | ↑ 2 | ↗ 1 | ↘ -1 | ↗ 1 | ↘ -1 |
| | 78 | Speed of certification and accreditation of new technologies | → 0 | ↗ 1 | ↓ -2 | ↗ 1 | ↑ 2 |
| | 79 | Speed of technology development for plant-based food products | ↑ 2 | ↗ 1 | ↘ -1 | ↗ 1 | ↗ 1 |
| | 80 | Use of climate-friendly technologies for fertilizer application | ↑ 2 | ↗ 1 | ↓ -2 | ↗ 1 | ↓ -2 |
| | 81 | Use of fossil-fuel based machinery | ↓ -2 | ↘ -1 | ↘ -1 | ↘ -1 | ↑ 2 |
| | 82 | Use of technologies for animal health | ↑ 2 | ↗ 1 | ↓ -2 | → 0 | → 0 |
| | 83 | Use of technologies for greenhouse gas emission monitoring | ↑ 2 | ↗ 1 | ↘ -1 | → 0 | ↘ -1 |
| Environment & Natural Resources | 31 | Animal health | ↑ 2 | ↗ 1 | → 0 | → 0 | → 0 |
| | 32 | Availability and quality of organic fertilizers | → 0 | → 0 | → 0 | ↗ 1 | → 0 |
| | 33 | Availability of agricultural land | → 0 | ↘ -1 | ↑ 2 | → 0 | ↗ 1 |
| | 34 | Biodiversity (genetic and species and ecosystem diversity) | ↑ 2 | ↘ -1 | ↓ -2 | ↘ -1 | ↓ -2 |
| | 35 | Land availability for animal nutrition and husbandry | ↓ -2 | ↘ -1 | ↗ 1 | → 0 | ↑ 2 |
| | 36 | Occurrence of communicable zoonotic diseases | ↘ -1 | ↗ 1 | ↘ -1 | ↗ 1 | ↗ 1 |
| | 37 | Share of agricultural land with cultivation restrictions resulting from nature protection | ↑ 2 | ↗ 1 | ↓ -2 | ↘ -1 | ↘ -1 |

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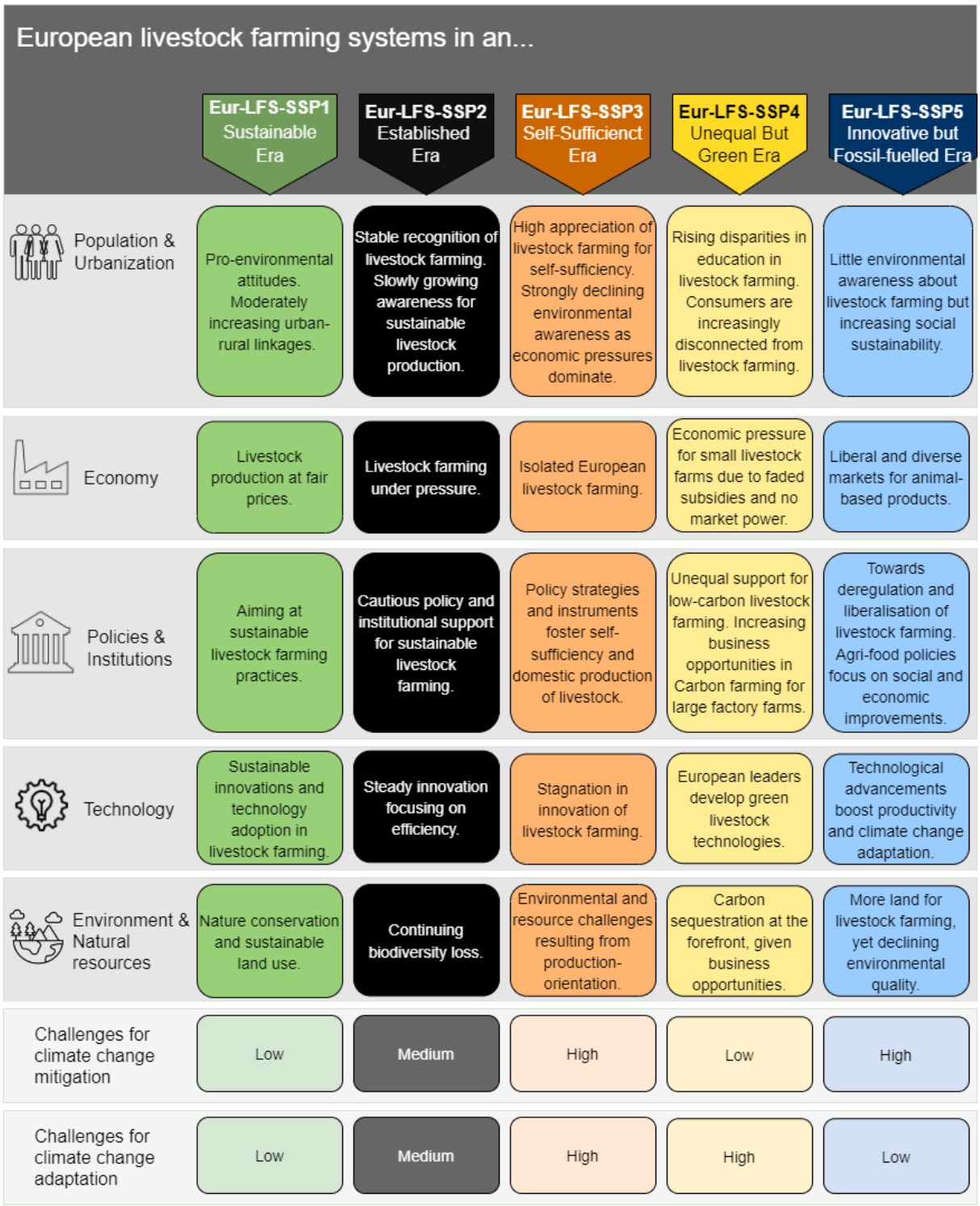
## 4.6. Summary of the Eur-LFS-SSPs

Figure 8 provides an overview of the five Eur-LFS-SSPs referring to the five topics and also summarizing the challenges for climate change mitigation and climate change adaptation.

**Figure 8:** Summary of the Eur-LFS-SSPs.

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# 4.7. Shared Socio-Economic Pathways for European livestock farming systems: the Eur-LFS-SSPs

## **Eur-LFS-SSP1:** European Livestock Farming Systems in a Sustainable Era

*Population & Urbanization: Pro-environmental attitudes and strong urban-rural linkages*

European livestock farming is driven by European citizens' high environmental awareness and societal expectations. Citizens show a very high interest in livestock farming. The awareness of animal welfare among citizens increases strongly, reflecting a society more conscious of ethical farming practices. This shift is accompanied by a growing appreciation of the agricultural work. Consumers and farmers recognize the critical contributions of livestock farming to sustainable food production, biodiversity conservation and the provision of ecosystem services including the preservation of valuable grasslands or genetic diversity. Citizens no longer see a need to increase societal pressure in form of protest movements as sustainable livestock production is achieved in Europe. Urban-rural linkages moderately increase which is shown by increased visits of cultural grassland landscapes or livestock farms by citizens. Citizens are increasingly aware of what animal welfare-oriented husbandry looks like and how to behave around livestock when visiting rural areas and farms. This reconnection fosters farmers' motivation and enhances their commitment to adopt sustainable livestock farming practices. The living standards of farmers and agricultural labour improve moderately, thanks to consumers' increased appreciation and higher farm incomes.

*Economy: Livestock production at fair prices*

Economic conditions in livestock farming improve such that the average income of livestock farmers and agricultural labour increase. Livestock farming becomes an attractive economic opportunity for family and small farms, as well as for larger farms and agri-investors. Consumers acknowledge that sustainable livestock production can be realized on small-scale farms but also on large farms while applying modern technology. Economic viability of livestock farms is mostly driven through higher commodity prices given the higher willingness to pay by consumers that compensates for additional production costs and improved working conditions. Consumers especially value high-quality, pasture-raised livestock products. Accordingly, per capita demand for animal welfare products rises. Yet, per capita demand for conventional animal-based food products decreases strongly. Consumers increasingly opt for unprocessed plant-based food products instead of cheap, imported, highly processed meat and milk-products and substitutes, driven by individual concerns related to human health and climate change. Venture capital-backed start-ups push dietary change by developing innovative food products that appeal to consumers seeking to reduce their ecological footprint. Relative prices of animal-based food products increase strongly, partly due to high taxes on livestock production and higher fixed costs of livestock farming, yet still allowing somewhat larger income for farmers and agricultural labour. Citizens are willing to pay the higher prices as they reflect the true costs of environmentally-, climate-friendly and fair livestock production. Imports of animal-based food products and animal feed decrease moderately from non-European regions because citizens prefer European food meeting high animal welfare, environmental and food standards. Trade within Europe increases to counterbalance different production conditions within Europe. Public and private investment volumes in animal welfare education and food literacy increase to meet consumers' demand and support farmers to bear the higher

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costs of welfare-oriented husbandry. Cattle is fed with roughage from extensively managed grassland and feed additives aiming to reduce the carbon intensity of livestock production. Besides traditional grassland-based livestock production, silvo-pastoral and agro-silvo-pastoral production- as examples of agro-forestry- gain in importance. Circular farming practices gain popularity, drawing interest from both farmers and citizens who value ecological and sustainable methods. For instance, free-range fattening pigs and willow also contribute to circular farming and soil fertility. However, circular farming falls short to provide enough input to enable crop production at targeted productivity levels across Europe due to declining livestock numbers as less animal-based food is demanded. Feeding local by-products, food leftovers and insects to pigs and poultry aims to support circular farming. Regionally produced manure is preferred to increase crop productivity and reduce the reliance on mineral fertilizers. Organic fertilizers like green manure, cover crops, crop residue recycling and composting, and biochar are fostered to substitute missing manure and, at the same time, support circular farming.

*Policies & Institutions: Aiming at sustainable livestock farming practices*

Political attention for climate change mitigation and adaptation in livestock farming increases strongly. Hence, policy strategies and instruments greatly stimulate the transformation of European livestock farming towards sustainability. Animal welfare standards rise and stringent environmental standards for livestock farming are implemented. A drastic reduction in the carbon budget for livestock farming is specified such that it contributes to climate change mitigation. Substantially higher carbon prices and taxes for non-$CO_2$ GHG emissions are introduced as well. The policy strategies and instruments, thus, support the internalization of external costs of livestock farming and incentivize sustainable farming practices like circular farming. The implementation of these policy instruments is supported through multi-level governance, i.e. stakeholder integration in the decision-making process, and strict monitoring and sanctioning. Accessibility to agricultural extension services for livestock farming improves significantly, enabling farmers to adopt animal welfare practices, environmental standards and innovative livestock technologies.

*Technology: Sustainable innovations and technology adoption in livestock farming*

Technological advancements for livestock production are integral to the transformation of European livestock farming towards sustainability. The degree of digitalization and automation in livestock farming increases significantly, enhancing the resource-use efficiency and reducing both the workload and the environmental impact livestock production. Climate-adaptive breeding and crossbreeding, as well as precision livestock farming become more prevalent, supported by strong acceptance and uptake among producers and consumers. Breeding also focuses on increasing productivity and animal feed efficiency of dual-purpose cattle, sheep and goat. Livestock husbandry and calf-rearing are enhanced to reduce nutrient losses, e.g. via feed and manure management. Additional feeding stations are installed at pastures where possible to support feeding additives and feed management. Innovative stable solutions are sought to enable plenty of open-air runs. The use of climate-friendly technologies for fertilizer application increases strongly to compensate for less available manure. Manure management efficiency improves, guided by nutrient management plans that align grazing schedules with the nutrient needs of a pasture, rotational grazing (i.e. dividing pastures into smaller paddocks to rotate livestock between them), and collecting manure near water, shade or additional feeding stations through portable manure collection systems. Manure

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management is supported by digital monitoring systems for greenhouse gas emissions on farms. Technologies for animal health and welfare are also widely adopted. These technological advancements lead to moderate increases in land productivity.

*Environment & Natural Resources: Nature conservation and sustainable land use*

Strict nature protection is prioritized and demanded by European citizens and policy-makers when necessary. Yet, sustainable food production is fostered by policies to ensure multifunctional landscapes. As a result, the share of agricultural land with cultivation restrictions resulting from nature protection increases strongly requiring extensive land use for several crop- and grasslands in Europe. Regulations also limit agricultural expansion into protected or natural areas including natural carbon reservoirs. The availability of agricultural land remains stable as multifunctionality is sought for most crop- and grassland, also for restoration of habitats like wetlands and peatland. In general, land use regulations prioritize plant-based food production, discouraging the use of arable land for feed and energy production or new infrastructure. Incentive-based measures strengthen the restoration of carbon sinks as well as climate- and biodiversity-friendly farming systems such as agroforestry and pasture cropping systems. Such integrated crop, livestock and forestry systems help to close nutrient cycles, strengthen biodiversity, reduce zoonotic diseases, and promote sustainable land use. Animal welfare and health improve significantly, thanks to advancements in animal husbandry and sustainable livestock farming practices. The quality of organic fertilizers increases strongly, supporting organic farming, yet the availability of manure declines.

*Conclusion: A sustainable future of European livestock farming systems*

European livestock farming integrates citizens' pro-environmental attitude and sustainability awareness, robust policies including economic incentives to achieve low climate change adaptation and mitigation challenges, low-carbon and environmentally-friendly technological innovations, and environmental stewardship. As consumer preferences shift towards plant-based foods, and as policies and technologies support these changes, livestock farming shrinks but achieves a balance between productivity and sustainability in 2050.

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## **Eur-LFS-SSP2:** European Livestock Farming Systems in an Established Era

### *Population & Urbanization: Stable recognition of livestock farming*

Citizens show a slowly growing awareness on animal-welfare and sustainable livestock production. This manifests in increased consumer attention for ecolabels and increasing food literacy which are supported by higher public investments in education. Appreciation for agricultural work by consumers remains constant, indicating a stable recognition in society that livestock farming is important. However, farmers' intrinsic motivation for livestock farming slightly decreases due to the challenges and pressures they face, like strengthened environmental standards, somewhat higher workloads and higher required technical skills for livestock farming while the financial compensation increases only slightly. Farmers are supported to gain expertise in technology as required in modern livestock farming systems via a better offer of agricultural extension services and higher investments in education. European education programs target in particular European countries where technological innovations have been implemented to a smaller extent. Furthermore, education programmes target farmers that face a gap concerning livestock productivity (e.g. for milk yields) aiming to close such gaps across Europe and across farmers within individual European countries.

### *Economy: Livestock farming under pressure*

Livestock farming is increasingly under economic pressure and competition in farming rises partly resulting from increasing imports from non-European countries. Farmers face higher variable costs and fixed costs given the increase in environmental and animal-welfare standards. Relative prices of animal-based food products also rise due to the taxes for non-$CO_2$ GHG emissions of livestock farming. However, consumers are only partly willing to pay higher prices for meat and milk. The market for novel foods for direct human consumption, including microbial and fungal-based products, expands somewhat. These novel foods often substitute conventional animal-based food products, while markets for animal-welfare food products grow. Overall, the market share of animal-welfare products increases while per capita consumption of animal-based products declines on average. Farmers are compensated for higher livestock production costs resulting from increasing standards via public subsidies allowing to remain livestock farmers income and income of agricultural labour stable. The demand for biogenic resources for biogas production is rising moderately on European average, reflecting a shift towards renewable energy sources. In some regions facing challenges to meet the renewable energy targets, biogas production from biogenic resources increases strongly. This shift towards renewable energy production is also shown through an increase in agri-PV installations on crop- and grassland enabling dual production of crops, livestock and energy. Manure is preferably used as organic fertilizer as the attractiveness of circular farming increases slightly. Although, the quality of organic fertilizers increases, the quantity slightly declines as livestock numbers decline in Europe. Thus, circular farming meets some limits here.

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*Policies & Institutions: Cautious policy and institutional support for sustainable livestock farming*

Policy strategies and institutional support aim to foster sustainable livestock farming, yet the implementation of policy instruments is rather unambitious. The political attention for climate change mitigation and adaptation increases slightly. It mainly results from further increased environmental and animal-welfare concerns manifesting in increasing societal pressure and more frequent protest movements for a sustainable transformation of livestock farming systems. Policymakers, thus, somewhat tighten the carbon budget for European livestock farming systems and introduce a moderate non-$CO_2$ tax for livestock farming. Environmental and animal welfare standards slightly increase, reflecting a slightly growing political and societal attention to environmental and ethical norms in livestock farming systems. European policies aim to reduce regional differences in productivity, environmental efficiency and carbon intensity of livestock production. For instance, farmers with above-average carbon intensities get access to additional educational support. In addition, subsidies for farmers aim at reducing their non-$CO_2$ GHG emissions and are financed by the tax paid by society.

*Technology: Steady innovation focusing on efficiency*

Technological advancements focus on resource use efficiency of livestock farming systems. Digitalization strongly increases within these systems, which improves productivity to some extent. Automation and climate-adaptive and cross-breeding techniques slightly improve, reflecting a cautious but steady integration of innovative practices in livestock farming systems. Feed efficiency is slowly growing, driven by innovations such as feeding novel proteins (e.g., insects), supplementing amino acids to feed, and precision feeding (i.e., blend feeding). The carbon intensity of livestock farming declines and manure management efficiency increases. This is due to innovations such as feed additives to foster animal carbon capture or the optimization of manure composition. To increase productivity and livestock health, digital twins are more often used in livestock farming systems. Indoor system practices improve as well like feeder design. Also, new animal behaviour tools are developed, aiming for instance at animating pigs. The use of climate-friendly technologies for fertilizer application increases to support sustainable livestock farming practices.

*Environment & Natural Resources: Continuing biodiversity loss*

The policy strategies and instruments as well as the technological innovations ensure to gradually reduce the environmental pressure from livestock farming. However, conservation efforts are too unambitious in combining livestock production and grassland conservation, leading to an overall loss in biodiversity. Therefore, the increasing share of agricultural land with cultivation restrictions for nature protection comes at the cost of extensive and marginal grassland available for animal nutrition and husbandry. This results in a reduction of the available agricultural land and increases the intensity of livestock farming on the remaining land. Land use regulations gradually shift to prioritize plant-based food production over growing crops to feed animals to meet increased consumer demand for plant-based food. Furthermore, land-based renewable energy production is fostered, like ground-mounted photovoltaic systems, increasing the competition for marginal grassland for biodiversity-friendly livestock production.

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*Conclusion: Known challenges for European livestock farming systems*

Overall, livestock farming systems face economic challenges due to the shifting consumer demands, animal-based food prices above consumers' willingness to pay, cautious policies aiming to internalize external costs, increasing environmental standards at constant renumeration for livestock farming, and steady technological advancements increasing required technical skills of farmers. These developments lead to slightly increased environmental pressures and medium challenges for climate change mitigation and adaptation.

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## **Eur-LFS-SSP3:** European Livestock Farming Systems in a Self-Sufficient Era

### *Population & Urbanisation: Appreciation of livestock farming*

Europe is facing economic stagnation, with threats of economic recession. As a result, living standards and income moderately decrease for a large part of the population, including farmers and agricultural workers. Although some European citizens might be still willing to pay for ecosystem services, e.g., animal welfare and climate change mitigation, the majority is no longer able to pay the additional costs of environmental-friendly and animal-welfare compliant livestock products. As a consequence, societal and political pressure for sustainable livestock production declines. In sum, the environmental awareness of European citizens strongly declines as the majority of citizens worries about the economic pressures. Additionally, societal, political and economic isolation and self-sufficiency are pushed by European citizens. Thus, citizens care about the contribution of livestock farming to self-sufficiency at the cost of biodiversity, ecosystem services provision, animal welfare and nature conservation. Consumers' attention to ecolabels declines moderately reflecting the declining concern for sustainable and environmental-friendly food products. The appreciation of agricultural work by consumers increases largely. This rise stems from a nationalistic sentiment encapsulated in campaigns like "our country, our farmers", emphasizing the importance of livestock farming for European nation's self-sufficiency.

### *Economy: Isolated European livestock farming*

The diversity of livestock supply chains strongly decreases due to strongly declining market integration and trade. European exports and imports of animal-based food products and animal feed, respectively, strongly decline. As a result, variable costs of livestock farming rise. This leads to a moderate increase of relative prices of animal-based food products. Farmers seek to adapt to rising input costs through manure trading in their regions within Europe. Manure is also demanded for biogas production, as the demand for biogenic resources for biogas production moderately increases given the declining availability and increasing prices of foreign natural gas and oil. Fixed costs of livestock farming remain stable due to relaxed environmental and animal-welfare standards. Because of declining incomes of citizens, consumers do not pay attention to high quality of food products but rather consume cheap and highly processed food products. Yet, they also demand domestically produced, conventionally produced animal-based and plant-based food products. The average per capita demand for animal-welfare, cultured animal-based products and processed meat and milk substitutes declines due to their high prices. This leads to less public and private investment in animal welfare. Demand for biogenic resources for biogas production increases moderately due to high energy prices resulting from less trade.

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*Policies & Institutions: Self-sufficiency in livestock farming*

Policies are characterized by a fragmented and uncooperative approach resulting in the isolation of European livestock farming systems from the rest of the world. Policy strategies and instruments foster self-sufficiency and domestic production of livestock. Financial support in the form of direct payments for livestock farming comes at the cost of environmental and animal-welfare standards and results in declining subsidies for the implementation of environmental-friendly and animal-welfare practices. Political attention to climate change mitigation and adaptation in livestock farming systems strongly declines as well. Neither carbon budgets for livestock farming systems, nor carbon prices or taxes for non-$CO_2$ GHG emissions of livestock farming are introduced since politicians aim to keep animal-based food prices low and because of declining environmental awareness of the society. Public investments in education and food literacy moderately decrease, due to a shrinking governmental budget prioritizing self-sufficiency over environmental and social concerns. Since there is no political or societal interest in environmental-friendly and sustainable food production practices, extension services are not commissioned in supporting farmers in these aspects. Rather, the services focus on increasing productivity and efficiency of livestock farming.

*Technology: Stagnation in innovation of livestock farming*

Technological advancements in livestock farming systems are slow due to less cooperation between international researchers, international trade, and investments in technology development given decreasing economic growth rates. Therefore, the speed and uptake of agricultural technologies moderately decrease, resulting in livestock farming systems that rely more on well-established methods and less on innovative solutions. Despite the constant availability of extension services to support farmers in particular to increase productivity and efficiency, there is only little progress in automatization and digitalization in livestock farming systems – mainly because the majority of farmers cannot cover the required investment costs and do not have the adequate knowledge. Technologies for animal health and husbandry are in use as long as possible but many farmers do not have the budget to reinvest in new equipment and investment subsidies are not provided. Climate adaptive breeding, alternative feeding technologies and climate-friendly technologies for fertilizer application are not successfully introduced due to market isolation, exacerbating the sector's vulnerability to climate change. The use of fossil-fuel-based machinery slightly decreases as prices for fossil fuels increase. However, farmers cannot afford to buy new machinery and technologies. As a result, important machinery is bought by state-owned companies from which farmers can borrow them when needed.

*Environment & Natural Resources: Environmental and resource challenges*

The share of agricultural land with cultivation restrictions for reasons of nature protection strongly decreases, resulting from reduced regulatory constraints on land use. Hence, biodiversity, natural habitats and habitat connectivity strongly decline. Public plans to reduce soil sealing and to put previously abandoned agricultural land back into production result in an increasing availability of agricultural land. This trend is in line with a moderate increase in the land available for animal nutrition and husbandry. Especially cropland for growing feed and food expands, which is needed given the lower imports. Nitrogen and methane emissions lead to environmental problems, such as deteriorating water quality. The occurrence of

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communicable zoonotic diseases moderately decreases as trade declines. Farmers and governments, however, face difficulties to deal with occurring diseases due to much less multi-level cooperation.

*Conclusion: National livestock farming for self-sufficiency*

Livestock farming systems are characterized by low technology adoption, traditional livestock farming methods, and a decrease in dietary diversity. Policies are tailored to self-sufficiency, with low international cooperation and little interest in environmental stewardship. As a result, challenges for climate change adaptation and mitigation are high.

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## **Eur-LFS-SSP4:** European Livestock Farming Systems in an Unequal but Green Era

### *Population & Urbanisation: Rising disparities in education in livestock farming*

Societal changes, increasing social disparities and growing power concentration in the agri-food value chain affect livestock farming systems in Europe. Increasing inequalities and lower public and private investments in education negatively affect the educational standards of the general population and of livestock farmers. For instance, the accessibility and quality of agricultural extension services and education programmes decline given less public funding for all education and extension programmes, including for livestock farming. Yet, the number of private high-level education centres for livestock farming increases. Here, programmes for farm managers and farm labour of large, profitable farms are offered and target especially technological expertise. Driven by these unequal education opportunities, the environmental awareness of citizens, including farmers, and food literacy of consumers decline for the majority. Only a small share of the population, the wealthy elite, profits from better education. Thus, citizens lose interest in environmental impacts of livestock farming leading to a moderately declining societal pressure for sustainable livestock farming systems. Consumers are increasingly disconnected from livestock farming, which is also shown by the decrease in the number and intensity of urban-rural linkages. This is also related to a decrease in the appreciation of agricultural work by consumers. Farmers themselves somewhat lose their motivation for livestock farming due to the declining appreciation and unequal opportunities to thrive economically as a farmer.

### *Economy: High economic pressure for small livestock farms*

Economic opportunities are very unequal in livestock farming systems, marked by a widening income gap. Farm managers of few, very large livestock farms experience increasing income, while the average income of agricultural workers and farm managers of the large number of small family farms declines. The oligopolistic market structure in livestock farming leads to high market concentration in favour of large, internationally operating livestock farms. Agri-investors own and control livestock farms, processors and retailers of livestock products leading to vertical integration and fewer actors. As a result, structural change further increases in livestock farming. High crude oil prices resulting from market concentration in the energy sector drive up relative prices of synthetic fertilizers. New technology companies enter the livestock farming system and merge with experienced livestock technology companies into large, internationally active companies that control the global market. Thus, market concentration in green technology development for livestock farming increases and the European companies are global leaders in this field. Continuous innovation in technologies such as livestock breeding lead to growing supply and demand capacities and stable prices. However, fixed costs of livestock farming increase since technology uptake is generally rising. Knowledge exchange, particularly among disadvantaged livestock farmers, also fosters technology uptake. Yet, farmers do not seek any other form of collaboration. Regional manure trading declines moderately as the number of livestock farms decreases continuously, given the high economic pressure for small family farms.

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Livestock farmers, who depend on feed and fertilizer purchases face higher variable costs given the high market power of seed and fertilizer companies and the oligopolistic market structure in the entire livestock farming system. Livestock farmers, who foster circular farming on their farms, face lower variable costs given lower labour input resulting from improved technologies, digitalization and automation. Relative prices of all food products, including animal-based food products, increase anyway, as the few retailers drive prices up given their high market power. Together with of livestock production, the relative prices of animal-based food products increase. Demand patterns of consumers change slightly, as the majority of consumers suffers from the prevalent economic disparities and has a rather low income and limited purchasing power. These consumers, which are facing low incomes and suffering from low education opportunities, do not care much about food quality, animal welfare, resource-extensive food production or plant-based diets but base their food purchasing decisions solely on the price. As a result, the majority of the population mostly consumes cheap, highly-processed food that is easy to prepare and only very rarely consumes the more expensive cultured food or plant-based, processed food like meat substitutes. The small group of citizens with high income consume high quality products, including animal-based products, mostly produced in Europe.

*Policies & Institutions: Unequal support for low-carbon livestock farming*

Institutions that govern the livestock farming system and set the respective political agenda at European level are dominated by economically successful managers of large, innovative livestock farms. The political attention shifts to the development and diffusion of green technology in livestock farming systems as Europe becomes a global leader in this field. Environmental sustainability and climate change adaptation and mitigation are not on the political agenda unless some policy instruments or regulations serve the interests of the large livestock farms shaping these policies. As livestock farmers see exciting business opportunities in carbon farming (e.g., silvo-pastures), they push the implementation of a more stringent carbon budget in livestock farming and the establishment of carbon markets. Yet, the allocation of the carbon budget is very unequal, favouring large livestock farms with disproportionately more rights for emitting GHG which increases their power in the carbon markets. The carbon credit system, which compensates for carbon sequestration on livestock farms with a moderately increasing carbon price, also mainly serves the economic interests of large farms. Formal standards for carbon sequestration are not introduced. Taxes on non-$CO_2$ GHG emissions, including methane and nitrous oxide, are implemented as well. For instance, the GHG emission intensity of large livestock farms and related taxes per unit of output are smaller due to higher technology uptake. Hence, efficient, large livestock farms have a comparative advantage with respect to the GHG emission taxes. Furthermore, the revenues of the non-$CO_2$ GHG tax are redistributed, whereby only highly efficient livestock farms receive subsidies. Animal welfare standards decline moderately, reflecting a reduced emphasis on ethical farming practices. Consumers and retailers are not willing to pay for animal welfare standards which lose relevance in global markets. As a result, research and development do not focus on them either. International trade agreements are strengthened, fostering global interactions and exchanges in livestock farming practices and products.

*Technology: European leaders develop green livestock technologies*

Technological advancements shape livestock farming systems. European companies develop into global leaders for green technologies in livestock farming as they see large business

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opportunities given high crude oil prices. In addition, they push technology developments to sequester carbon and reduce GHG emission intensity of livestock farming, and they use emerging business opportunities. Precision livestock farming and the use of digital twins become more prevalent, highlighting the sector's shift towards high-tech solutions. However, the economic benefits of these technologies are unevenly distributed. Only few, large-scale, livestock farms can access ground-breaking breeding, feeding and manure management technologies to reduce the GHG emission intensities of livestock farming given that rather high investment cost cannot be met by the small family farms. Advanced automation technologies lead to a reduced need for manual farm labour on these farms. The majority of farmers does not have the expertise and financial capacity to gain from the substantial advancements in technologies. This technological divide further exacerbates social and economic inequalities within livestock farming systems.

*Environment & Natural Resources: Carbon sequestration at the forefront*

The increasing extent of carbon sequestration practices often comes at the expense of non-energy crops, i.e. food and feed crops, and pastures. The large livestock companies earn carbon credits for carbon sequestration projects implemented mostly in Eastern Europe. Biodiversity slightly decreases. Yet, restoration projects to sequester carbon and gain carbon credits, like rewetting of peatland, also have co-benefits for biodiversity conservation and reduce the speed of biodiversity loss to some extent. The availability and quality of organic fertilizers including manure increases as it becomes an important substitute for very expensive synthetic fertilizers.

*Conclusion: Unequal but green European livestock farming systems*

Overall, livestock farming systems face high economic disparities with only the large, innovative European livestock farms benefiting from economic and technology developments. The green technology advancements and the boost of carbon sequestration lead to low climate change mitigation challenges. These elite farms are driven by economic interests, and the low mitigation and environmental challenges are therefore only rather a side-product. Yet, rising social disparities and limited economic opportunities result in high climate change adaptation challenges for many livestock farmers.

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## **Eur-LFS-SSP5:** European Livestock Farming in an Innovative but Fossil-fuelled Era

*Population & Urbanisation: Little environmental awareness about livestock farming in society*

European citizens share the vision of technology-driven economic development with equal opportunities for all. High economic growth rates, also in livestock farming systems, support high living standards. Public investments in education and food literacy remain stable. The investments are targeted to boost technology expertise in livestock farming. Societal beliefs are that technology and economic liberal systems will solve all environmental and climate related issues via technological adaptation and end-of-pipe solutions. Accordingly, society has little interest in environmental stewardship given its technology-focus. Hence, societal pressure for environmentally sustainable livestock farming systems is low. Accordingly, the attractiveness of circular farming declines strongly among farmers and citizens. Yet, citizens and farmers ask for fair livestock farming systems with high social sustainability.

*Economy: Liberal and diverse markets for animal-based products*

Competition increases within and along the agri-food value chain including input suppliers, technology companies, farmers, processors and retailers in the entire livestock farming systems. The rapid technological advancements and the high competition between technology companies lead to a significant decrease in the relative prices of livestock breeding technology and variable costs of livestock production. Fixed costs of livestock farming decline slightly due to relaxed environmental and animal welfare standards and the more affordable digitalization and automation technologies given fast innovation cycles. Large farms with the financial capacity to invest in technology may benefit disproportionately from technological advancements, gaining somewhat more market share. Average income of agricultural labour increase strongly and of livestock farmers moderately, driven by policy regulations for fair working conditions, and the reduction in variable and fixed costs. Yet, high competition and declining food prices negatively affect farm margins to some extent. Average income of livestock farmers still increases moderately given that cost savings are larger than income reductions. However, cattle and dairy farmers, as well as sheep and goat farmers suffer from higher competition and clearly face lower farm margins than in other livestock farming systems. Deregulation and international trade are fostered, resulting in growing European export and import of animal-based food products and animal feed. Agri-investors and large farms profit from deregulation. As a result, the pace of structural change in livestock farming increases moderately. Average per capita food demand increases in Europe as rising economic growth rates positively affect consumers' purchasing power. In addition, consumer diets get more diverse and exotic. The demand for high-quality animal-based and plant-based products remains on high levels, both in the EU internal and international markets. Stronger international trade agreements favour increasing trade volumes and the attractiveness of livestock farming in Europe. Domestic demand for cultured animal-based food products and highly processed food like processed meat and milk substitutes rises sharply due to increasing consumer's technology acceptance. Yet, the production of cultured meat does not compete with conventional animal-based products as the average per capita meat consumption remains constant across Europe.

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*Policies & Institutions: Towards deregulation and liberalisation of livestock farming*

Institutions play an important role in the rapidly evolving landscape of livestock farming systems in particular via deregulation. Market deregulation is prominent, as policymakers and society follow a technology-driven, liberal economic pathway, also in livestock farming systems. Agri-food policies focus on social and economic improvements such as fair working conditions and stable income, whereas environmental effects of livestock farming are of little concern. The combination of a liberal economic pathway with these societal goals and political objectives result in relaxed environmental and animal welfare standards, also allowing for the expansion of arable land into previously protected areas. Public and private investments in animal welfare see a decline accordingly. The focus on liberalization, technological progress and economic growth even hinders the development and implementation of policy instruments focusing on climate change mitigation in livestock farming systems including carbon budgets, carbon prices or taxes for non-$CO_2$ GHG emissions. Agricultural extension services focus on technological development aiming only at improving productivity and cost-effectiveness but not on climate and environmental issues, thus reflecting the limited interest of policymakers and society in climate change mitigation and the environment.

*Technology: Technological advancements boost productivity and climate change adaptation in livestock farming*

Technological advancements substantially change European livestock farming systems – targeting automatization and digitalization as well as productivity, animal feed efficiency and climate change adaptation, while disregarding natural resource-use efficiency and carbon-intensity. Cheap crude oil fosters fossil-fuel driven technological innovations also in livestock farming. By contrast, climate-friendly technologies for organic fertilizer application are rarely used because synthetic fertilizers are cheap and thus preferred. This reflects the societal ignorance of climate change mitigation. The speed of agricultural technology development accelerates, supported by high levels of technology acceptance by producers and consumers and deregulation of technologies. This leads, for instance, to innovation in GMO and gene editing, allowing effective climate change adaptation and a boost of climate-adaptive breeding. Indoor, landless livestock farming, including feeding novel proteins and using precision feeding technologies, is fostered as it is more compatible with automated livestock husbandry. Furthermore, indoor livestock farming practices are optimized for climate change adaptation, utilizing big data and AI for farm decision-making. Pasture-raised livestock and circular farming, thus, loose attractiveness. Livestock is increasingly fed with crops, novel feeds and feed additives including insects.

*Environment & Natural Resources: More land for livestock farming*

Societal concern about the environmental impacts of livestock farming is low. This is reflected by the moderately decreasing share of agricultural land with cultivation restrictions due to nature protection, making more land available for animal nutrition and husbandry. Combined with relaxed environmental standards, this leads to a strong decrease in biodiversity. Manure management technologies focus on easing the handling and management of manure for indoor farming. Farmers do not value manure or manure management efficiency given cheap synthetic fertilizers. This also results in less regional trade of manure. Where available, high amounts of manure are applied per hectare, increasing the problem of nitrogen emissions into soil, water and atmosphere. Overall, the relaxed environmental standards lead to lower

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compliance costs of livestock farming. However, society meets fairly high overall costs for implementing technological solutions, which are required to balance declining environmental quality, like declining soil health. These technological solutions enable intensive livestock production on a continuous basis – also because certain environmental impacts are simply ignored as long as no negative human health consequences occur. The occurrence of communicable zoonotic diseases increases as trade channels and volumes of livestock and animal-based products increase substantially. Yet, negative effects on animal health can be avoided given the rise in technology development and uptake.

*Conclusion: Fossil-fuel driven innovations for European livestock farming systems*

Livestock farming systems are characterized by deregulation and technological advancements that boost productivity and lead to high livestock production intensities at the cost of environmental health. Livestock farming systems face high challenges for climate change mitigation, though adaptation measures are more readily developed and adopted, driven by economic rather than environmental concerns.

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## 4.8. Stakeholder feedback

### Evaluation of collaboration

Most participants agreed (strongly) that the workshop content and tasks of workshops 2 were clearly explained (83%), as shown in figure 9. Although the majority of the participants of workshops 1 and 2 also agreed (strongly) that the expectations of the workshops were met (55%), 39% disagreed and 6% strongly disagreed here. Mentioned reasons were that the workshop schedules were rather tight, and the time for the individual task was limited. The participants would have appreciated more time, also allowing deeper discussions of the scenario logics and individual developments within a scenario.

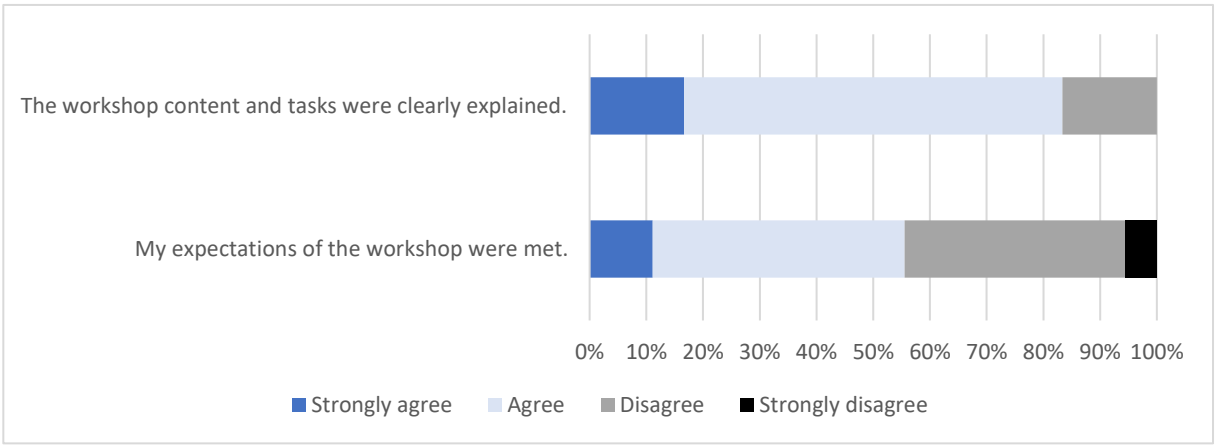


**Figure 9:** Relative responses of workshop participants on clarity and expectations of the workshop (n=6 for clarity and n=18 for expectations).

### Perceived usefulness of the scenarios

Participants of the workshops were asked whether the workshop presentations and discussions are relevant for the stakeholders' daily work. In total, 19 persons rated the question on flipcharts during the two workshops. Figure 10 shows the respective results. The majority of participants (60%, 11 persons) agreed (strongly) that the workshop presentations and discussions were relevant for their daily work. Nevertheless, 4 persons (20%) strongly disagreed. Mentioned reasons for disagreeing were, for example, that time constraints did not allow for detailed discussions of individual scenario elements and their developments, which would have been of particular interest for the stakeholders' daily work. Furthermore, the stakeholders argued that the scenarios themselves are quite complex, and details of individual scenarios as well as differences between the scenarios are not easy to grasp.

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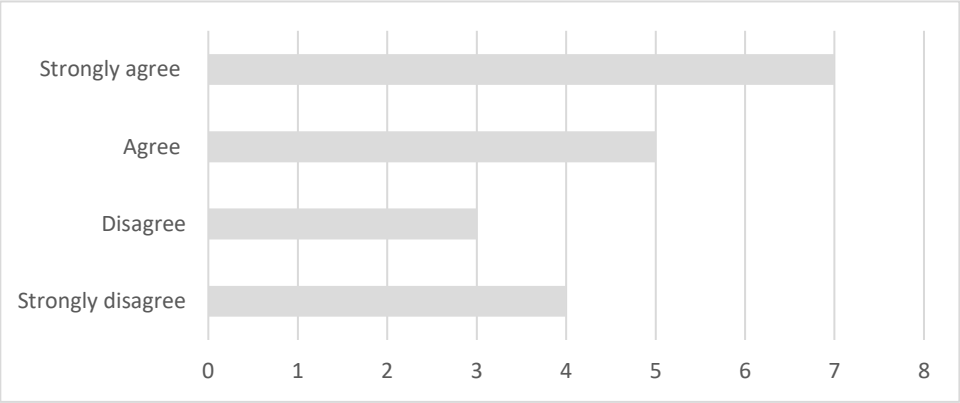


**Figure 10:** Count responses of workshop participants on the relevance of workshop presentations and discussions for their daily work, n=19.

The stakeholder review of the scenarios (working step 7) also included a question about the usefulness of the Eur-LFS-SSPs for the daily work of the stakeholders. Table 9 summarizes the answers from the stakeholder review and gives further insights why the scenarios are or are not considered useful. For the review, stakeholders had several weeks of time. Thus, stakeholders did rarely criticize time constraints or scenario complexity, in contrast to workshop participants. In summary, stakeholders see value for focusing future research projects, for discussing potential challenges or identifying societal or research questions (like the environmental impact of processed plant-based and animal-based products), and for integrating the scenarios in university teaching.

**Table 9:** Stakeholder comments on the usefulness of the Eur-LFS-SSPs for their daily work.

| Stakeholder comment | SSP reviewed |
|---|---|
| To integrate this scenario into my daily work as a researcher in the livestock sector in Mediterranean Spain, I would align my research projects with emerging trends and technological advancements. This includes focusing on climate-adaptive livestock farming, precision livestock farming, and sustainable innovations. Furthermore, I would strengthen collaboration with policymakers and other stakeholders to develop and implement regulations that enhance animal welfare, reduce carbon emissions, and promote sustainable farming practices. Moreover, I would prioritize adopting and disseminating digital technologies in livestock farming by demonstrating the benefits of precision farming and training farmers on using these technologies to enhance resource-use efficiency and reduce environmental impact. Lastly, I would incorporate more sustainability metrics into my research and extension activities to monitor and report on the impacts of different livestock farming practices on the three pillars of sustainability. | 1 |
| Difficult question. As a researcher I can identify relevant questions from this scenario and analyse important factors and drivers and find solutions for barriers. But it is mainly a political decision where we want to go. What (aspects of) different scenarios we strive for or want to realise. | 1, 4 |
| As a researcher and extensionist, I would have to separate some main points of this scenario so it could be integrated into my daily work. Increment in animal welfare and sustainable production can be easily integrated into my daily work. However, considering plant-based products equal nutritionally and sustainably without any sciences that back this statement up would be almost impossible. It would start with the farmers' and stakeholders' discussions on how these two opposite worlds could happen simultaneously and be equally beneficial for humanity. | 1 |
| The scenario would be very useful as a starting point for what we would like to achieve with sustainability and what might happen – what are the challenges. It would work as a useful scenario in teaching as well. | 1 |
| I think this scenario is useful together with the other scenarios, as a starting point for future projects and for discussions with students. | 1 |

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| | |
|---|---|
| I think this scenario may make us think about where and how we want to get there. | 1 |
| Forward looks are always important but to reflect my work there would need to be more detail on natural resources especially the soil. | 2 |
| Since this is a real scenario for some European realities, it could help to ask whether it is okay like this, whether we have already reached the desired level or not. | 2 |
| For me as a lecturer:<br>Such scenarios are great to communicate to students that our decisions today can affect the long term effect in Europe, especially how we decide to perceive the livestock farming and the farmers will have massive consequences on access to food but also on economy and technology, not to mention legislation.<br><br>For me as a scientist:<br>Evaluation of possible outcomes of my work. Possibility to perform experiments that would prove to policy makers that certain changes are needed or would have negative consequences. | 3, 4 |
| I can use this scenario with students to let them experiment with the dynamics of policy decision making, and communicate to them that today's decisions will have long-term effects on the EU food systems, with consequences on EU's economy, innovation systems and finally citizens. This scenario can be used as a starting point in foresight exercises for defining the "desirable" scenario stakeholders would like to achieve in the future. These exercises can be carried out at different geo-political scales, therefore promoting reflections on agri-food policies at different levels. | 3, 5 |
| I think this scenario is useful together with the other scenarios, as a starting point for future projects and for discussions with students. | 3 |
| A scenario that makes you think a lot, and that opens various debates on trying to understand how not to get to this point. A good example of what not to do. | 3 |
| Difficult question. As a researcher I can identify relevant questions from this scenario and analyse important factors and drivers and find solutions for barriers. But it is mainly a political decision where we want to go. What (aspects of) different scenarios we strive for or want to realise. | 4 |
| Interesting scenario, and quite plausible. So it allows to be analyzed and used as an example | 4 |
| Overall, it would be challenging to include this narrative in my current working scheme. However, I would focus on fostering collaborations with technology companies, policymakers, and livestock farmers, thus trying to find a balance between economic growth and environmental sustainability. Additionally, integrating research on sustainable practices and animal welfare, adopting an interdisciplinary approach and strengthening agricultural extension services would be necessary to ensure a holistic approach that complements the presented narrative. | 5 |
| In my current work, this scenario is an example of what we do not want to happen/to do. It would be a good narrative to explain/show why keeping the sustainable production enhancement momentum is important and what things producers, scientists, and environmental stakeholders can do to avoid this scenario. | 5 |
| This could be used as a worst-case scenario for increased fossil fuel use and loss of biodiversity. A useful contrast to what could be changed to adapt the industry. | 5 |

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# 5. Discussion and Conclusions

In this report, five contrasting, plausible scenarios for European livestock farming systems, the Eur-LFS-SSPs, are presented. They were developed in a participatory process engaging, in total, 153 stakeholders through semi-structured interviews, workshops, group discussions or in the peer and stakeholder review. The stakeholders suggested 80 scenario elements, representing key drivers of changes in European livestock farming systems. The scenario elements are clustered along five topics: “Population & Urbanisation”, “Economy”, “Policies & Institutions”, “Technology”, and “Environment and Natural Resources”. In the following, the participatory scenario development process as well as the newly developed scenarios are discussed.

## Scenario development process

The scenario elements and the relationships between the scenario elements were identified in a participatory process based on the principles of cognitive mapping which resulted in a system diagram of the European livestock farming systems. The chosen methodological approach proved useful to develop legitimate and consistent scenarios, two of the defined quality criteria. Yet, challenges arose during the researcher-driven aggregation of several cognitive maps that have been developed in parallel, in particular with respect to identifying indirect drivers or relationships. Other researchers experienced similar challenges (Kropf et al., 2021; Olazabal et al., 2018) and suggested to follow pre-defined rules in the aggregation process (e.g. Harper and Dorton, 2019; Siau and Tan, 2008). Hence, we differentiated between six categories (e.g., causal, conditional, consecutive) describing the relationships between the scenario elements. This allowed us to extract the causal relationships between the scenario elements, which were finally included in the system diagram. This approach ensured to build on stakeholders’ perceptions (i.e., legitimization) and, at the same, kept the system complexity (i.e., number of scenario elements and relationships) manageable.

## Reflections on the use of artificial intelligence (AI)

An AI chatbot was used to derive very first drafts of the narratives of the Eur-LFS-SSPs. Inputs to the AI chatbot included (i) the development directions of the scenario elements for each Eur-LFS-SSP (e.g., medium/strong increase/decrease, constant development), as defined in the stakeholder workshops and checked for consistency, and (ii) a document summarizing important developments in each Eur-LFS-SSP, which was based on the transcripts of the workshop discussions focusing on key actors, innovations, and developments in each Eur-LFS-SSP. The very first drafts of the narratives were carefully checked and revised by two researchers. We learned that the chatbot tended to include normative statements in the narratives (which were removed) and that the derived first drafts for Eur-LFS-SSP1 and Eur-LFS-SSP2 with low or medium challenges for climate change adaptation and climate change mitigation necessitated less (though still substantial) revision by the researchers, compared to the other three very first draft narratives. In the revision process, a particular focus was put on the quality criteria specified for scenario development in the beginning. Revisions also included a more detailed description of the relationships among scenario elements, the description of relevant examples for livestock farming systems as discussed in the workshops, and linguistic improvements to improve clarity and readability. Thus, the status quo of the AI chatbot was not suitable as a single source for narrative writing in context of the SSPs.

## Stakeholder engagement

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A diverse group of stakeholders actively contributed to scenario development, representing different types of organizations, various European countries and genders. While we aimed for a balanced representation, participants from Eastern Europe, from policy-making as well as females were more difficult to reach and engage. By contrast, scientists from Central and Western Europe are dominant. This is to be considered as we may miss specific voices and perspectives in the narratives.

With respect to country representation, we successfully engaged stakeholders from across Europe even if the share of Eastern European participants was disproportionally low. However, the final Eur-LFS-SSPs represent average developments across Europe and do not describe detailed regional differences. Hence, this imbalance might be less relevant for the final output.

With respect to the involved types of stakeholders, a large number of scientists contributed to the scenario development process. This is, to some extent, due to the chosen setting of the second and third workshops, which took place during a conference and a consortium meeting. We used these opportunities to reach large groups of scientists, policymakers, NGO representatives, farmers and farm representatives as well as industry professionals working on livestock farming systems in Europe. While the workshop participants are experts in the fields of technology in livestock farming, agricultural economics, and sustainability assessment and, hence, broadly covered the topics to be addressed in the narratives, we were less successful with reaching representatives from policy making and industries, leading to a dominance of scientists. To some extent, this imbalance was corrected by engaging students as well as farmers and farmer representatives via group discussions. However, participation in all activities was voluntary and the particular interest of scientists also indicates the potential relevance of the scenarios for further research and teaching.

The stakeholders were asked to give feedback on the workshops. They criticized tight workshop schedules combined with faced time constraints. Similar criticism is frequently encountered in stakeholder activities (Gramberger et al., 2015). Hence, balancing between intensive engagement without risking that stakeholders refuse participation remains a challenge. Setting priorities in terms of stakeholder engagement seems necessary, also in the context of stakeholder fatigue experienced in other research processes (Gramberger et al., 2015). Overall, stakeholders evaluated the scenarios and the scenario development process as useful for their daily work, in particular if stakeholders work in science and education.

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## The Eur-LFS-SSPs

The five Eur-LFS-SSPs consist of a narrative and a table with the development direction of the 80 scenario elements. Stakeholders contributed to the definition of new scenario elements, compared to the existing Eur-Agri-SSPs. Fifteen scenario elements were taken from the Eur-Agri-SSPs, as the stakeholder suggested similar ones. New scenario elements are, for instance, “Food literacy of consumers” and “Animal welfare awareness of citizens” in the topic “Population & Urbanisation”. In the topic “Economy”, stakeholders suggested, for instance, “Per capita demand for conventional animal-based food products”, “Per capita demand for animal welfare products”, “Variable cost of livestock production” and “Fixed costs of livestock production” as new scenario elements. “Carbon price”, “Taxes for non-$CO_2$ GHG emissions driven by livestock farming systems”, “Public investment volumes in animal welfare” and “International standards for carbon sequestration” are new scenario elements in the topic “Policies & Institutions”. In the topic “Technology”, stakeholders suggested, for instance “Animal feed efficiency”, “Climate adaptive breeding”, “Degree of automatization in livestock farming systems” and “Interoperability of technologies” as new scenario elements. In the topic “Environment & Natural Resources”, new scenario elements are, for instance, “Animal health”, “Availability and quality of organic fertilizer”, “Biodiversity” and “Land availability for animal nutrition and husbandry”.

Graph analysis of the system diagram allows to identify the scenario elements, which influence most others. These are: “Variable cost of livestock production”, “Societal pressure for sustainable livestock farming systems”, “Environmental standards”, “International trade agreements” and “Environmental awareness of citizens”. Focusing on these scenario elements gives a quick overview on the main differences among the five Eur-LFS-SSPs. For instance, “Variable costs of livestock production” remains constant in Eur-LFS-SSP1, the scenario representing low challenges for climate change mitigation and climate change adaptation. This scenario element moderately increases in Eur-LFS-SSP2, 3 and 4. By contrast, it strongly decreases in Eur-LFS-SSP5 with low challenges for climate change adaptation but high challenges for climate change mitigation. In general, it is characterized by deregulation, liberal and open markets and a continued use of fossil fuels, which results in lower costs and prices. This is also consistent with Eur-Agri-SSP5, which specifies generally decreasing variable costs in agri-food systems (Mitter et al. 2020).

“Societal pressure for sustainable livestock farming systems” remains constant in Eur-LFS-SSP1. This is mainly because political goals in terms of sustainable livestock farming are achieved and society no longer sees a need to further increase the pressure. In contrast, societal pressure increases moderately in Eur-LFS-SSP2. In the other Eur-LFS-SSPs, “Societal pressure for sustainable livestock farming systems” declines as certain aspects of sustainability are less relevant in these scenarios.

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"Environmental standards" and "Environmental awareness of citizens" have the same development directions in the respective Eur-LFS-SSPs. For instance, in Eur-LFS-SSP1 both increase strongly. In Eur-LFS-SSP2 both increase moderately. In Eur-LFS-SSP3 and 4 both decrease moderately. In Eur-LFS-SSP3 this moderate decrease is due to a strong focus on self-sufficiency and economic pressures in terms of lower economic growth and lower income – resulting in the deliberate ignorance of some environmental problems and, thus, some relaxation of environmental standards. "Environmental awareness of citizens" declines as less funding is available for education, and environmental problems are rarely part of the public and political discourse. In Eur-LFS-SSP4, the moderate decline in environmental awareness results of a deterioration of education infrastructure and very uneven access to education. "Environmental standards" moderately decrease in Eur-LFS-SSP4 as policymaking follows the interest of large livestock farms which often opt for relaxed environmental regulation unless they see business opportunities, like in carbon markets. In Eur-LFS-SSP5, both scenario elements strongly decrease. This results from a societal orientation and belief towards industrial solutions for environmental problems and free, open markets with minimum political intervention.

Finally, the development direction of the scenario element "International trade agreements" shows differences in the five Eur-LFS-SSPs as well. In Eur-LFS-SSP1 and 2, it increases moderately. However, in Eur-LFS-SSP1 trade takes mostly place within Europe while trade with non-European countries decreases. In Eur-LFS-SSP3, "International trade agreements" decrease strongly as Europe fosters self-sufficiency and international political and economic isolation. In Eur-LFS-SSP4 and 5, this scenario element increases strongly, given a strong international market orientation in both scenarios.

## In short

Overall, the participatory development of contrasting, yet plausible Shared Socio-economic Pathways for European livestock farming systems, proved successful despite of some experienced challenges, as discussed above. The newly developed scenarios may inform policy-making processes, extension services, teaching and research – as also highlighted by the stakeholders participating in the peer and stakeholder review. Stakeholders also suggested to discuss the newly developed scenarios with respect to normative European policy goals and trajectories towards these goals. Thus, future research could focus on the question of how to potentially realize the required developments of the most influential drivers of the European livestock farming systems.

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# Appendix

## Stakeholder review of the narratives

### Evaluation questions

1) How **clear and comprehensible** is the Eur-LFS-SSP1 narrative? Which relationships or developments are unclear or incomprehensible to you? Please comment your rating.
1 = not at all clear and comprehensible, 5 = very clear and comprehensible

2) How **plausible** is the presented view on the future of European Livestock Farming Systems until 2050 in the Eur-LFS-SSP1 narrative? Which descriptions are implausible from your point of view? Please comment your rating.
1 = not at all plausible, 5 = very plausible

3) How **consistent** is the text on the Eur-LFS-SSP1 narrative in itself? Which of the described drivers, events, developments or relationships do you consider to be inconsistent? Please comment your rating.
1 = not at all consistent, 5 = very consistent

4) How **rich in detail** is the Eur-LFS-SSP1 narrative? To what extent are the **specifics** of the European Livestock Farming Systems addressed in the SSP1 narrative? In your opinion, what other specifics of the European Livestock Farming Systems should be addressed in the SSP1 narrative? Please comment your rating.
1 = not at all rich in detail and not at all addressing specifics, 5 = very rich in detail and addressing specifics

5) How appropriate is the title and acronym for the Eur-LFS-SSP1 narrative? What alternative title or acronym would you suggest?
1 = not at all appropriate, 5 = very appropriate

6) How can you use the scenarios for European Livestock Farming Systems in your daily work? What additions would be necessary to enable you to integrate the scenarios for European Livestock Farming Systems into your daily work?

### Review questionnaire for SSP1

1) How **clear and comprehensible** is the Eur-LFS-SSP1 narrative? Which relationships or developments are unclear or incomprehensible to you? Please comment your rating.
1 – not at all clear and comprehensible, 5 = very clear and comprehensible

| Rating | Comment Stakeholder | Response Researchers |
|---|---|---|
| 4 | The Eur-LFS-SSP1 narrative is straightforward and understandable. It outlines the relationships and developments in European livestock farming systems transitioning towards sustainability. The narrative clearly describes the shift in public attitudes towards pro-environmental behaviours. The role of political attention in driving sustainability through stringent animal welfare and environmental standards is clearly stated. Furthermore, it explains the declining demand for conventional animal-based products, increased prices for sustainable food products, and the prominent role of technological advancements in | The benefits of agroforestry, as well as the impacts of declining livestock numbers on manure availability were taken up in the narrative somewhat more precise and detailed. |

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| | livestock farming, such as digitalization, automation, precision livestock farming, and circular farming practices.<br><br>However, the benefits of integrating agroforestry (free-range fattening pigs and willow) must be further described. Furthermore, the impact of declining livestock numbers on the availability of manure for crop production is mentioned. Nevertheless, the implications of this decline on overall agricultural productivity could be more precise. | |
| 4 | I agree with the above comments that the Eur-LFS-SSP1 narrative is in general<br>clear and comprehensible. The developments towards sustainability are described as being driven by a changed awareness/expectation of citizens. This changed citizens attitude is taken as a starting point of the scenario and I wonder where/how the transition from the current situation is addressed (what made citizens attitude change?).<br><br>I also miss a bit that, as a result of the described 'reconnection', consumer views are more 'realistic' and they understand that AW is not only realised on romantic small-scale farms but can be realised through application of modern technology, and improvements made possible through higher consumer prices. They also recognise that farmers have to make a living and that has a price for consumers. | All five narratives of the Eur-LFS-SSPs compare a situation of the livestock farming systems in 2050 with their current situation. The narratives do not illustrate particular trajectories how to reach them. Also, this is part of a different task in Re-Livestock ().<br><br>These aspects are now included in the narrative. |
| 4 | While the Eur-LFS-SSP1 narrative is clear and understandable, it presents potential challenges that require further exploration. The scenario envisions a future where citizens' awareness about animal welfare and sustainable production increases, leading to a willingness to pay extra for animal products. However, there are certain points in the narrative that may need further explanations, particularly in terms of the economic viability of livestock farming and the feasibility of a sustainable era in all European regions.<br><br>- How can livestock farming become an attractive economic opportunity at a small or bigger scale if there is an increase in the number of consumers of plant-based food products? Is this scenario raising the idea of two different consumers (i.e., animal and plant-based food products)?<br>As a nutritionist, I am concerned about the narrative's strong assertion that the increase in plant-based food | In our view this is not a contradiction. Consumers still demand meat, but less, from high quality and exclusively produced in Europe (and not imported). Yet, average per capita meat demand declines – as it is rather high in Europe in a global comparison. Therefore, plant-based food products |

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| | products is driven by human health and environmental concerns. As a scientist, I am equally troubled by the claim that this switch is more environmentally friendly. We currently lack sufficient evidence to support these statements, which underscores the need for further research in this area.<br>- This scenario states a very strong sustainable era. However, not all European regions are equal, and plant-based or animal-based food would be equally distributed across Europe. For example, it is mentioned that cattle are mainly fed with hay from extensive grassland management, and traditional grassland-based livestock production, silvo-pastoral and agro-silvo-pastoral, gain in importance. How would that be possible in more marginal regions where the landscape and the climate result in more challenging plant and animal production systems? Will these regions not be productive anymore? If so, what would happen to the population, and how much carbon footprint will it cost to feed these people? | are increasingly demanded to compensate for less consumed meat. So, consumers demand more plants but also are willing to pay more for the meat that they consume. We tried to make this clear in the narrative.<br><br>The scenario does not suggest that all developments are the same across Europe. Rather, these are average changes. It would go too far to describe differences among regions but we tried to mention that different developments are possible within Europe. |
| 4 | The scenario is clear and comprehensible apart from the way an increasing environmentally/sustainable educated population would question the production of livestock/milk products but not any plant-based production system, especially how sustainable these were on more marginal land currently used for grazing. | We tried to include that plant-based production systems are also questioned, in particular if it is about highly processed food products. Also, the scenario does not suggest that grassland is converted to cropland. |
| 4 | I agree with all the comments above. Two points:<br>1. The heading “Economy: Reduced extensive livestock production at fair prices” is unclear. What is reduced? Is production from extensive systems in general reduced or production from extensive systems with fair prices? Or is the proportion receiving fair prices that is reduced? That is not in accordance with the content of this paragraph.<br>2. How can manure management become more efficient when more animals are on pasture? | The sub-heading was changed.<br><br>We elaborated more on manure management efficiency in the narrative. |
| 4 | The scenario is very clear and comprehensible. All the relevant categories are analysed; social, economic, political, technological…. | |

2) How **plausible** is the presented view on the future of European Livestock Farming Systems until 2050 in the Eur-LFS-SSP1 narrative? Which descriptions are implausible from your point of view? Please comment your rating.
1 – not at all plausible, 5 = very plausible

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| Rating | Comment Stakeholder | Response Researchers |
|---|---|---|
| 3 | The presented view in the scenario reflects a comprehensive and optimistic approach towards sustainability driven by societal, economic, and technological changes. However, while there is a growing trend towards environmentally friendly consumption, the assumption that most consumers will consistently pay higher prices might be overly optimistic. Economic disparities and varying consumer priorities could result in a more mixed response. Furthermore, while implementing stringent environmental standards is a plausible scenario, their practical implementation might face strong resistance from various stakeholders, including farmers, industry lobbyists, and even consumers, who may find the resulting price increases a big problem.<br>The assumption that urban-rural linkages will increase significantly and that citizens will develop a deep understanding and appreciation of livestock farming practices may be too optimistic. Given the current trends (sustained over the last decades) of depopulation of rural areas, the increase of these linkages seems very optimistic without a complete paradigm shift. In this sense, The expectation that European consumers will exclusively consume domestically produced food that meets high standards is somewhat implausible.<br>In all, some narrative elements may need to be moderated to reflect potential obstacles and a more incremental progression towards sustainability. | We do agree about the mixed responses regarding economic disparities, but as mentioned above, we refer to average developments in the narrative. Discussing such differences would require too many details.<br><br>The limitations of practical implementation are expected to be overcome in this scenario given high multi-level governance and monitoring. We tried to describe this better in the narrative now.<br><br>We do agree and changed it to a moderate increase of urban-rural linkages. We relaxed the last aspect a bit by stating that the majority of consumed food is produced in Europe. |
| 2 | As commented above, the scenario depends on a realised change in citizens attitude. The indicated strong increase of political attention for climate change mitigation and adaptation in livestock farming systems is only realised if the changes in citizens attitudes towards livestock farming are realised.<br>I consider the realisation of that change until 2050 not very plausible. | We agree that the mentioned links are very relevant and very strong for the described narrative. However, we are somewhat unsure whether the described developments are indeed implausible or if they are rather unlikely? |
| 2 | As I mentioned before, unless science proves that plant-based products are healthier for human consumption and can be produced more sustainably than animal-based products, I cannot see this scenario as plausible by 2050. | See above |
| 3 | Some of this scenario is plausible, however, without some of the other details it is not that clear. | The scenario described European livestock systems where consumers |

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| | Additionally, it is good that sustainability would be increased but a greater reliance on plant-based food may well have its own challenges for the environment especially if imported from outside the EU. Are milk replacement products more sustainable? Would a more educated population not start to question this? Finally, any reduction in food production would have to be balanced as the same or slightly growing global population would still need to be fed. How would this part of the scenario? | demand the majority of food, including plant-based food products, produced within Europe and not imported.<br><br>We briefly describe now that consumers are also critical about plant-based processed food (see comment above).<br><br>The scenario focuses clearly on Europe – but food waste reduction can be relevant here. |
| 2 | I cannot see how a free market would manage to perform such a fundamental change, and political governance has until now been very vague. I'm pessimistic… | The scenario does not describe a political and market framework which is liberal and unregulated. Regulation is of key importance here – as also mentioned in comments above. Again – is it indeed implausible or rather unlikely? |
| 2 | This scenario is not very plausible, especially in several respects. It is implausible that the market for insects will expand; our culture is too far from eating insects. Only by making a policy of knowing the possible benefits and making it clear that the products will aesthetically be the same as 'conventional' ones could one possibly succeed in increasing the market. It is true that the presence of more and more different ethnic groups, where the food in question is used on a daily basis, could favour this scenario.<br>Decreasing exports and imports is not plausible, we would return to an extremely closed market, where we only proceed with self-sufficiency production. In many countries this, in my opinion, is not sustainable, both for the presence of the products in sufficient quantities, but also to sustain the entire population.<br>It is not plausible for me to go more and more towards utilisation of hay by decreasing the use of concentrates and/or feed. With the climatic changes taking place, the difficulties in obtaining hay increase dramatically (sudden unseasonal rains, extreme heat...).<br>I agree that public opinion is becoming more and more attentive to concepts such as animal welfare and environmental impact, and that technologies (even if for some sectors in some countries, e.g. in Italy for sheep milking technology is not as advanced as for cattle) are becoming more and more advanced to guarantee standards.<br>I agree that right from schools there should be education about food and how it is produced. But | We agree with your comments regarding the markets for insects. We changed this in the narrative now.<br><br>We tried to better describe that trade with non-European countries decreases but European countries trade with each other.<br><br>We agree with your concerns regarding hay. We incorporated your remarks now in the narrative. |

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| | very often people who choose not to eat meat in preference to vegetables have not been educated properly. This makes meat appear to be a bad food and the farming conditions unfair. | This scenario is not against meat production but for sustainable meat production. We tried to make that clear in the narrative. |

3) How **consistent** is the text on the Eur-LFS-SSP1 narrative in itself? Which of the described drivers, events, developments or relationships do you consider to be inconsistent? Please comment your rating.
1 – not at all consistent, 5 = very consistent

| Rating | Comment Stakeholder | Response Researchers |
|---|---|---|
| 4 | There are a few areas where the narrative could benefit from further clarification. The text notes that circular farming practices gain popularity but fall short of providing enough input for targeted crop productivity levels due to declining livestock numbers. This point could be further elaborated to explain how the system compensates for the reduced availability of manure and other organic fertilizers, thus increasing the currency of the ideas conveyed. | We clarified the mentioned aspects in the narrative now. |
| 3 | As indicated above: I struggle with the realisation of the main driver which is citizens attitude. | Please see our response above. |
| 2 | Again, I cannot see a link/consistency between an increasing demand for plant-based products and a willingness to pay more for animal-based products simultaneously and stating that both are as good for human consumption as their production is equally sustainable. | Please see our response above. |
| 4 | Overall, there is a general consistency to the scenario but the changes in costs and farmers/labourers wages doesn't appear consistent. As initially it is sated that the incomes improve moderately but later it states costs of produce increases as a result of environmental taxes – in this case the increased cost would not benefit the farmers income but may even decrease it as the government through taxes is taking any extra income. | We elaborated on these aspects more in the narrative. |
| 4 | It's consistent, but it's easy to be consistent in a dream world | |
| 4 | In itself the scenario in all the aspects it touches is very coherent, it does not make contradictions | |

4) How **rich in detail** is the Eur-LFS-SSP1 narrative? To what extent are the **specifics** of the European Livestock Farming Systems addressed in the SSP1 narrative? In your opinion, what other

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specifics of the European Livestock Farming Systems should be addressed in the SSP1 narrative? Please comment your rating.
1 – not at all rich in detail and not at all addressing specifics, 5 = very rich in detail and addressing specifics

| Rating | Comment Stakeholder | Response Researchers |
|---|---|---|
| 4 | While the narrative is thorough, additional specifics could further enrich the SSP1 scenario. The first one is the farm-level/size challenges. In this sense, more detail on specific challenges faced by petite vs. large farms in transitioning to sustainable practices (directly linked to the intensification process experienced by the sector). Furthermore, more information is needed on how this scenario will implement specific strategies for farmer education and training in sustainable practices and new technologies. In addition, more insights are necessary about the potentially existing market mechanisms that support sustainable livestock farming, such as subsidies, grants, or incentive programs for sustainable practices, as well as information on the impacts of these newly presented livestock farming systems on biodiversity and specific ecosystem services. | While we agree with the points made by the reviewer, we need to balance the length between the scenarios. |
| 4 | I think the level of detail is good. Some points as mentioned by the first reviewer could be included. | |
| 3 | The narrative is overall well-detailed. It would help if the points described in question 1 were more detailed. | |
| 4 | There is a useable level of detail to much of the scenario description a few more points could have been elaborated, such as 'Cattle husbandry and calf-rearing are enhanced to reduce nutrient losses.' It would be good to have some more detail here. | We tried to provide a few more details for cattle husbandry and calf-rearing. |
| 4 | The scenario is rich enough for cattle but I miss pigs&poultry since they can play important roles in circular food systems | We tried to incorporate pigs and poultry more. |
| 3 | The scenario is quite rich, but it does not take into account the sheep/goat breeding system for example, where for some areas these represent the majority of livestock farming | We tried to incorporate sheep/goats more. |

5) How appropriate is the **title and acronym** for the Eur-LFS-SSP1 narrative? What alternative title or acronym would you suggest?
1 – not at all appropriate, 5 = very appropriate
Eur-LFS-SSP1: European Livestock Farming Systems in a Sustainable Era
Eur-LFS-SSP2: European Livestock Farming in a Conventional Era
Eur-LFS-SSP3: European Livestock Farming in a Food Sovereignty Era

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Eur-LFS-SSP4: European Livestock Farming in an Unequal Green Era
Eur-LFS-SSP5: European Livestock Farming in an Innovative Fossil-fuelled Era

| Rating | Comment Stakeholder | Response Researchers |
|---|---|---|
| | I like that the titles are framed similarly for all five narrative. I wonder if “systems” should be deleted in SSP1 for reasons of consistency. | We instead included systems in the four other scenarios. |
| 5 | For me the present title is clear The title "European Livestock Farming Systems in a Sustainable Era" and its acronym "Eur-LFS-SSP1" effectively capture the essence of the narrative | |
| 5 | Title seems ok. | |
| 5 | Title is OK. | |
| 5 | The title is fine, but I agree the removal of the word ‘Systems’ from SSP! would create a consistency. | |
| 5 | I also agree | |
| 5 | I agree with the title, it gives a very good idea of what it says | |

6) Additional stakeholder comments in the narrative text.

| Comment Stakeholder | Response Researchers |
|---|---|
| Pigs and poultry can also play important roles in circular farming since they eat waste and by-products and feed from insects fed with waste and by-products. | We included this in the narrative. |
| The heading is unclear; what is reduced? Is production from extensive systems in general reduced or production from extensive systems with fair prices? Or is the proportion receiving fair prices that is reduced? That is not in accordance with the content of this paragraph. | We agree and changed the heading to “Livestock production at fair prices”. |
| In this sense, and in my personal opinion, it is unlikely that insects are compared with laboratory-produced meats or vegetable protein substitutes. I think we have been hearing for many years that these foods are coming (insects). However, this has never translated into increased consumption. That is why I believe that the future horizon (2050) is very unrealistic. | We agree and changed this development and description in the narrative text. |

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| Eating insects is not an alternative to eating farm animals for consumers believing strongly in animal rights. I think insects fits into this scenario mostly from the circular perspective, but eating insects fed of food waste or manure is problematic from a food hygiene perspective. | |
| hay or silage is not the point - is it? | We agree with the suggested change of “roughage”. |
| This [manure management efficiency improves] will be difficult if most animals are on pasture most of the time. | We agree that the description how such an improvement is feasible in SSP1 was not detailed enough. We extended it therefore. |

Review questionnaire for SSP2

1) How **clear and comprehensible** is the Eur-LFS-SSP2 narrative? Which relationships or developments are unclear or incomprehensible to you? Please comment your rating.
1 – not at all clear and comprehensible, 5 = very clear and comprehensible

| Rating | Comment Stakeholder | Response Researchers |
|---|---|---|
| 4 | The scenario is mainly clear but ‘Environmental and animal welfare standards slightly increase, reflecting a slightly growing political and societal attention to environmental and ethical norms in livestock farming systems.’ Is not clear if the policy would be driving this or the environmental and animal welfare? | We tried to clarify what is driving the increase in environmental and animal welfare standards in the narrative. |
| 4 | Very clear and well analysed scenario | |

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2) How **plausible** is the presented view on the future of European Livestock Farming Systems until 2050 in the Eur-LFS-SSP2 narrative? Which descriptions are implausible from your point of view? Please comment your rating.
1 – not at all plausible, 5 = very plausible

| Rating | Comment Stakeholder | Response Researchers |
|---|---|---|
| 4 | The reduction in the loss of both marginal and intensive grassland from environmental conservation restrictions. These outcomes could also be facilitated by restrictions on fertiliser and lime use to control $CO_2$ emissions and the farm carbon footprint. | |
| 4 | Plausible scenario, some realities might be at this point. So for these realities we may already be further along in 2050. But at EU level for many countries we are far from this scenario today. | We tried to better describe that there are some differences within Europe. |

3) How **consistent** is the text on the Eur-LFS-SSP2 narrative in itself? Which of the described drivers, events, developments or relationships do you consider to be inconsistent? Please comment your rating.
1 – not at all consistent, 5 = very consistent

| Rating | Comment Stakeholder | Response Researchers |
|---|---|---|
| 3 | The section ‘’Policies and Institutions: Cautious policy and institutional support for sustainable livestock farming’ appears to be the most inconsistent as it is unclear who is driving this – animal welfare concerns, policy or environmental concerns? | We tried to include more details and describe respective drivers better. |
| 3 | Perhaps the part on policy analysis contains few details that give a good understanding of the mechanism | See above |

4) How **rich in detail** is the Eur-LFS-SSP2 narrative? To what extent are the **specifics** of the European Livestock Farming Systems addressed in the SSP2 narrative? In your opinion, what other specifics of the European Livestock Farming Systems should be addressed in the SSP2 narrative? Please comment your rating.
1 – not at all rich in detail and not at all addressing specifics, 5 = very rich in detail and addressing specifics

| Rating | Comment Stakeholder | Response Researchers |
|---|---|---|
| 4 | In general, the correct level of detail has been achieved. Any more detail and it could be suggested that the scenarios would become too specific. However, a little more detail on how some of the outcomes would be achieved would be useful such as ‘The demand for biogenic resources for biogas production is rising slightly, | We tried to broaden the aspect of renewable energy production on arable land or with crops, besides bioenergy production in the narrative, e.g. by describing agri-photovoltaic systems. We, however, do not see major technological challenges here, as in |

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| | reflecting a shift towards renewable energy sources.' As the demand may rise but the technology needs to be developed to facilitate this. | some European countries, respective technology developments are pushed forward already. |
| 3 | Quite a lot of detail, where I don't think specific examples are given (e.g. animal breeding systems or types of technologies and innovations) | The details available from the workshops were used. However, in contrast to other scenarios, nothing specific was described for SSP2. |

5) How appropriate is the **title** and **acronym** for the Eur-LFS-SSP2 narrative? What alternative title or acronym would you suggest?
1 – not at all appropriate, 5 = very appropriate
Eur-LFS-SSP1: European Livestock Farming Systems in a Sustainable Era
Eur-LFS-SSP2: European Livestock Farming in a Conventional Era
Eur-LFS-SSP3: European Livestock Farming in a Food Sovereignty Era
Eur-LFS-SSP4: European Livestock Farming in an Unequal Green Era
Eur-LFS-SSP5: European Livestock Farming in an Innovative Fossil-fuelled Era

| Rating | Comment Stakeholder | Response Researchers |
|---|---|---|
| | I think that conventional is very much related to farming but may also be misunderstood. Alternatives could be traditional, conservative etc. | We agree. We used "Established" now, as traditional is also associated with a particular form of farming. "Conservative" could be associated with nature conservation or conservation agriculture. |
| 4 | 'conservative era' would be more suitable. | See above |
| 4 | Very featable. The title that might fit best is conventional, but could be misrepresented | See above |

6) Additional stakeholder comments in the narrative text.

| Comment Stakeholder | Response Researchers |
|---|---|
| Change development direction of +1 to 0 for Attractiveness of circular farming or farmers and citizens. | We kept +1 and formulated it as a slight increase in the narrative which meets limits because of less manure availability. Because +1 is in line with increasing environmental awareness, environmental standards etc. |
| Change development direction of 0 to -1 for Living standards of farmers and agricultural labour | We kept 0 because working conditions and income for agricultural labour and livestock farmers are also 0 to ensure consistency here. |
| Change development direction of +1 to +2 for Demand for biogenic resources for biogas production | A +2 for Europe on average seems to us a lot. But it can be plausible that in some European regions this scenario element strongly increases – so we have included this in the narrative now. Also we included an increase of other renewable energy sources on arable land, like agri-photovoltaic systems. |
| Change development direction of 0 to -1 for Eur-Agri-SSP: labour supply in agriculture | For the Eur-Agri-SSP scenario elements we kept the values from the respective paper as these talk about developments in agri-food systems in general and not only in the livestock farming systems. So |

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| | we ensured consistency with the Eur-Agri-SSPs here. |

Review questionnaire for SSP3

1) How **clear and comprehensible** is the Eur-LFS-SSP3 narrative? Which relationships or developments are unclear or incomprehensible to you? Please comment your rating.
1 – not at all clear and comprehensible, 5 = very clear and comprehensible

| Rating | Comment Stakeholder | Response Researchers |
|---|---|---|
| 5 | The concept of SSP3 is very clearly explained. I do not see the need to extend any of the aspects. I have suggested the publication for the further investigation of the possible technologies that could be used in the less technologically driven era of farming. | We have considered your suggestions. |
| 4 | The description of SSP3 is very clear and comprehensible. do not see the need for further extension of the text. However, I have only suggested some changes and re-wording to make sure it is fully clear even to un-expert readers. | We have considered your suggestions. |
| 4 | The narrative is clear, but much shorter than SSP1 which I read before this one. If SSP1 is a dream world, this is a dystopia and I miss an explanation of *why* European citizens no longer care for the environment or animal welfare. Is this a scenario of hunger in Europe? That should be explained. | We have expanded such aspects to hopefully make the overall scenario logic clear and to align all five scenarios in terms of length. |
| 4 | Very clear scenario, and also sad to imagine I would say. | |

2) How **plausible** is the presented view on the future of European Livestock Farming Systems until 2050 in the Eur-LFS-SSP3 narrative? Which descriptions are implausible from your point of view? Please comment your rating.
1 – not at all plausible, 5 = very plausible

| Rating | Comment Stakeholder | Response Researchers |
|---|---|---|
| 1 | Currently the European citizens are very well aware of the need for animal welfare and reducing the agriculture environmental footprint. We are much more often ready to pay more for food, but to be certain about its source. At the same time I am worried that the work of the farmer is not appreciated enough in terms of money and citizens awareness.<br>Since in my opinion the consumers will not shift away from animal welfare awareness the remaining element of the scenario are also very unlikely to follow. | Yet, the aim was to develop a set of plausible scenarios and not likely scenarios. In our view, the next stakeholder comment summarizes the scenario logic very well. |
| 3 | Currently, the attention to sustainable production | We appreciate that the scenario |

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| | | |
|---|---|---|
| | systems and animal-welfare are quite high in Europe. However, we are facing a period of economic stagnation (with threats of economic recession of big EU countries such as Germany). This would imply living standards and income decrease for a large part of the population which, although willing (maybe) will not be able to pay the additional costs of environmental-friendly and animal-welfare compliant livestock products. This will then decrease societal and political pressure on ecolabels and sustainable production practices. Additionally, societal, political and economic isolation and self-sufficiency will also be pushed by EU citizens. | logic was well summarized here and was apparently clear. |
| 3 | I'm afraid it could happen, if climate change (with more extreme weather) leads to lower yield and increased hunger. | We interpret this that it is plausible. |
| 3 | Unfortunately, I don't think this scenario is so unrealistic. It is true that the EU is paying a lot of attention to animal welfare and sustainable production, but if there are no economic subsidies for farmers at the base this could be the future. The recent wars could increase the sense of nationalism, wrongly. | We interpret this that it is plausible. |

3) How **consistent** is the text on the Eur-LFS-SSP3 narrative in itself? Which of the described drivers, events, developments or relationships do you consider to be inconsistent? Please comment your rating.
1 – not at all consistent, 5 = very consistent

| **Rating** | **Comment Stakeholder** | **Response Researchers** |
|---|---|---|
| 5 | The concept of SSP3 is very clearly and consistently explained. I do not see the need to extend or clarify any of the aspects. | |
| 4 | Overall, SSP3 description is very consistent. I have some reflections about a few of them which I left in the comments. | We incorporated the respective comments. |
| 4 | It is consistent but some information about the background is missing | We incorporated some more details in this scenario. |
| 4 | Very clear and consistent. Not more to add. | |

4) How **rich in detail** is the Eur-LFS-SSP3 narrative? To what extent are the **specifics** of the European Livestock Farming Systems addressed in the SSP3 narrative? In your opinion, what other specifics of the European Livestock Farming Systems should be addressed in the SSP3 narrative? Please comment your rating.

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1 – not at all rich in detail and not at all addressing specifics, 5 = very rich in detail and addressing specifics

| Rating | Comment Stakeholder | Response Researchers |
|---|---|---|
| 4 | In my opinion there is enough information to follow the concept of this scenario and why one aspect of citizens' perception can affect the changes in legislation, economy, technology and environment. Surely there could be more written (that is why "4"), but it is not needed to understand the scenario. | We included some more details to balance the length between the five scenarios. |
| 5 | In my opinion, enough information is provided. | |
| 3 | Since I started by reading SSP1 I find this one too short to stimulate my curiosity - it doesn't tell "a full story". I would like some more examples and explanations. | We included more examples and explanations. |
| 4 | Details quite present | |

5) How appropriate is the **title** and **acronym** for the Eur-LFS-SSP3 narrative? What alternative title or acronym would you suggest?
1 – not at all appropriate, 5 = very appropriate
Eur-LFS-SSP1: European Livestock Farming Systems in a Sustainable Era
Eur-LFS-SSP2: European Livestock Farming in a Conventional Era
Eur-LFS-SSP3: European Livestock Farming in a Food Sovereignty Era
Eur-LFS-SSP4: European Livestock Farming in an Unequal Green Era
Eur-LFS-SSP5: European Livestock Farming in an Innovative Fossil-fuelled Era

| Rating | Comment Stakeholder | Response Researchers |
|---|---|---|
| 4 | Adding the "self-sufficiency" to the title would help to get the reader the full vision of the presented scenario. | We agree that self-sufficiency is the better term and changed it accordingly. |
| 5 | In my opinion, the title fully summarise SSP3 narrative | |
| 5 | The title is OK | |
| 5 | Right title, I wouldn't suggest an alternative | |

6) Additional stakeholder comments in the narrative text.

| Comment Stakeholder | Response Researchers |
|---|---|
| Why - what causes this decline [of environmental awareness]? | We added a brief explanation. |
| I do not fully grasp how the political situation described above does affect the "accessibility" to extension services.<br>In my opinion, a more effective storyline would be that, "since there is no political and societal | We agree and tried to incorporate the mentioned aspects. |

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| | |
|---|---|
| interest in eco-friendly and sustainable food production practices, extension services are not interested in supporting farmers transition toward sustainable livestock production practices"<br><br>In brief, accessibility does not change, but extension services do not support farming systems innovation, but rather keep with their business-as-usual.<br><br>However, in this case, I would see productivity and efficiency (only economic) to be positively affected. They will probably keep to increase, but at a lower rate since the market isolation.<br><br>If all this is fine, will move the considerations about extension services in the "technology" session | |
| More information is needed here - how would manure trading work in practice? It's complicated for single farmers to export manure (which has large volume) across country borders. | Yes, this is true. Within Europe suggests large distances, therefore, we reworded such that it becomes clear that manure trading takes places within smaller regions within Europe. |
| I think "traditional" here is confusing [technology]. You mean the rely on the methods they already have, don't you? | We agree and changed the wording. |
| For me this is quite not plausible. The digital transition is started and do not think will stop.<br><br>However, the point we could make here is that this transition is target to the "business-as-usual" objectives meaning productivity and economic efficiency (through the reduction of variable costs) rather than be targeted to environmental and animal-welfare objectives. | We agree. However, we think that the speed would be still less in this scenario. We anyhow changed the wording. |
| Why only for fertilizers application?<br><br>Other technologies with might be "not successful" increasing the sector's vulnerability to climate change are the alternative feeding technologies, which can fail due to market isolation and the reliance only on crops, food wastes, ect. only produced in Europe. | We agree with your comment and incorporated it as suggested. |
| What about nitrogen and methane emissions?<br><br>In my opinion, they will both increase since there will be more land for animal nutrition and husbandry. However, the increased emissions of nitrogen could be somehow compensated due to the increased requests for biogenic material for biogas production | We tried to incorporate the suggested comments. |

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| | |
|---|---|
| I think the ongoing structural change towards less number of farms but larger size of farms will be extra fast in this scenario? | Yes, this could be expected without any additional political support. The Eur-Agri-SSPs assume that there are some political subsidies which counteract faster structural change. |

## Review questionnaire for SSP4

1) How **clear and comprehensible** is the Eur-LFS-SSP4 narrative? Which relationships or developments are unclear or incomprehensible to you? Please comment your rating.
1 – not at all clear and comprehensible, 5 = very clear and comprehensible

| Rating | Comment Stakeholder | Response Researchers |
|---|---|---|
| 5 | The concept of SSP4 is very clearly explained. I do not see the need to extend any of the aspects. The fact that in my opinion it is a very plausible scenario also makes it easier for me to believe the description. | |
| 3 | I find some of the described relationships between developments not very convincing. For example, why does less public and private investments in education result in a declined accessibility of agricultural extension services? And why do unequal education opportunities lead to a decline of environmental awareness of ALL citizens and s decline of food literacy of ALL consumers? I would expect to see these declines in groups with limited access to education. | We included a brief explanation for the drivers of less investment in education and the effects on extension services.<br>We agree- unequal education opportunities are not given for all citizens but for the majority. We clarified this now. |
| 5 | very clear and well explained | |

2) How **plausible** is the presented view on the future of European Livestock Farming Systems until 2050 in the Eur-LFS-SSP4 narrative? Which descriptions are implausible from your point of view? Please comment your rating.
1 – not at all plausible, 5 = very plausible

| Rating | Comment Stakeholder | Response Researchers |
|---|---|---|
| 4 | Highly possible scenario as we are already observing many aspects of it in Europe:<br>- high pressure on low environmental impact of agriculture<br>- favouring big farms over smaller farmers<br>- growing disconnect of the consumers from agriculture | |
| 3 | Less plausible because of above mentioned reasons | See comment above. |
| 4 | Quite a plausible scenario.<br>I was struck by the discussion about the distance of cities from the agricultural world, even just for road connections, it's true. | |

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3) How **consistent** is the text on the Eur-LFS-SSP4 narrative in itself? Which of the described drivers, events, developments or relationships do you consider to be inconsistent? Please comment your rating.
1 – not at all consistent, 5 = very consistent

| Rating | Comment Stakeholder | Response Researchers |
|---|---|---|
| | low environmental awareness and pressure on livestock farmers vs. the introduction of carbon markets? I think it is important to strengthen the argument that “the elite farmers” are driven by economic interests and environmental benefits are a “side-product” | We agree and incorporated the mentioned aspects even more in the narrative. |
| 4 | I agree with the comment above. Still I find the text of SSP4 consistent | |
| 3 | see point 1. Not clear what part of consumers suffers from the economic disparities and how this affects the demand for quality food, ethically and resource-extensive produced food, organic food etc. | We included a brief explanation what part of consumers suffer from economic disparities and respective effects. |
| 4 | Coherent scenario and well explained and supporting drivers and barriers | |

4) How **rich in detail** is the Eur-LFS-SSP4 narrative? To what extent are the **specifics** of the European Livestock Farming Systems addressed in the SSP4 narrative? In your opinion, what other specifics of the European Livestock Farming Systems should be addressed in the SSP4 narrative? Please comment your rating.
1 – not at all rich in detail and not at all addressing specifics, 5 = very rich in detail and addressing specifics

| Rating | Comment |
|---|---|
| 4 | The concept of SSP4 is very clearly explained. I do not see the need to extend any of the aspects. The fact that in my opinion it is a very plausible scenario also makes it easier for me to believe the description. |
| 3 | needs detail concerning above points |
| 5 | Very rich in detail |

5) How appropriate is the **title and acronym** for the Eur-LFS-SSP4 narrative? What alternative title or acronym would you suggest?
1 – not at all appropriate, 5 = very appropriate
Eur-LFS-SSP1: European Livestock Farming Systems in a Sustainable Era
Eur-LFS-SSP2: European Livestock Farming in a Conventional Era
Eur-LFS-SSP3: European Livestock Farming in a Food Sovereignty Era
Eur-LFS-SSP4: European Livestock Farming in an Unequal Green Era
Eur-LFS-SSP5: European Livestock Farming in an Innovative Fossil-fuelled Era

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| Rating | Comment |
|---|---|
| | When having the SSPs in mind, I do not fully understand the “green” in the title - is this because of low mitigation challenges? However, it becomes more clear after reading the narrative. |
| 5 | Title is correct and explains what comes in the description. |
| 3 | I don’t understand the ‘green’ either |
| 2 | Do not understand either me “green” |

## Review questionnaire for SSP5

1) How **clear and comprehensible** is the Eur-LFS-SSP5 narrative? Which relationships or developments are unclear or incomprehensible to you? Please comment your rating.
1 – not at all clear and comprehensible, 5 = very clear and comprehensible

| Rating | Comment Stakeholder | Response Researchers |
|---|---|---|
| 4 | The overall scenario is well-articulated and easy to follow, though certain relationships and specific impacts could benefit from further elaboration. While the narrative states that circularity and animal welfare standards decline, it is not entirely clear how this reduction impacts specific aspects of livestock farming. In addition, the increase in communicable zoonotic diseases is mentioned but not elaborated upon. I personally don’t see the link to this fact in the framework of this scenario. | The consequences for the declining circularity and animal welfare standards are now partly discussed in the narrative. We tried to include more details on the mentioned aspects and elaborate somewhat more on the increase in communicable zoonotic diseases. |
| 4 | I agree with the above comment. It would also be beneficial to explain further the increase in communicable zoonotic diseases. It could happen due to the greater demand and animal movements, but with the rise in technology implementation, it would be easier to avoid these. | See above. We agree that it would be easier to avoid negative consequences from them and incorporated this in the narrative. |
| 4 | The scenario is generally clear with a few areas that could be improved. Would food policies include wages and fair working conditions of open to competitive innovation? Would there not be natural curbs on production, even with technological innovation, as parts of the landscape becomes more difficult to cultivate i.e. reduced soil health? | We tried to elaborate on the consequences of more difficult cultivation conditions a bit more. |
| 4 | The scenario is overall well-articulated and linear. Only a few areas can benefit from further articulation (see my comments). In particular, the role of extension services and the global market liberalisation could be more precisely described.<br><br>For example, what would be the effects of the | We tried to describe these aspects somewhat better. |

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| | | |
|---|---|---|
| | combination of increased technological development and reduced environmental standards on the internal EU market? | |

2) How **plausible** is the presented view on the future of European Livestock Farming Systems until 2050 in the Eur-LFS-SSP5 narrative? Which descriptions are implausible from your point of view? Please comment your rating.
1 – not at all plausible, 5 = very plausible

| **Rating** | **Comment Stakeholder** | **Response Researchers** |
|---|---|---|
| 3.5 | In the current context of increasing economic neoliberalism, the paradigms presented by this narrative can be plausible to a certain extent. While the process of intensification and specialisation we are observing may lead to potential deregulation, increased productivity, and greater use of technologies, it is not very plausible for me that it will simultaneously eliminate existing environmental and animal welfare regulations. | See below. |
| 3 | Animal welfare, digitalization, technology implementation, and sustainable production awareness are increasing daily, and I do not see a very plausible scenario where this trend switches. It may take longer than 2050 to fully understand and implement sustainable production with a lower carbon footprint, but I see it impossible to stop this trend. | See below. |
| 3 | It is plausible to a certain extent but without knowing how technological advancements would be able to rectify problems that it had caused it is difficult to know the full outcomes. The increased wages in the sector maybe a factor but cheaper inputs and competition may well reduce overall margins and even though the consumer may be richer it doesn't immediately follow they will pay more for their food. | All narratives are not very detailed regarding certain outcomes as these are typically output of integrated models.<br>We took your comment regarding input and farm margins into account. |
| 4 | The SSP is plausible especially for what concerns neoliberal policies and markets, technology-driven intensification and specialization. What I found less plausible is the foreseen path of environmental, animal-welfare and climate deregulation (compared with the current conditions). I think to make increase the plausibility on this regard, it can be useful to specify that society and political beliefs are that technology and economic liberal systems will solve all environmental and climate related issues. | We have included the suggested comment to improve the plausibility. |

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3) How **consistent** is the text on the Eur-LFS-SSP5 narrative in itself? Which of the described drivers, events, developments or relationships do you consider to be inconsistent? Please comment your rating.
1 – not at all consistent, 5 = very consistent

| Rating | Comment Stakeholder | Response Researchers |
|---|---|---|
| 5 | This narrative is quite consistent, emphasising a technology-driven, economically focused livestock farming system with minimal concern for environmental and animal welfare issues. The narrative cohesively ties together various elements, such as high economic growth, increased investment in education and technology, and a societal preference for deregulation and liberalisation. | |
| 5 | The narrative is consistent. | |
| 4 | Mainly consistent but I would consider the raise in wages but also stating that costs of production will decrease. This would affect farm margins and not drive up wages. | We have taken up the mentioned aspects. |
| 4 | The narrative is consistent. I would only suggest to provide more details on the issues highlighted in my comments | |

4) How **rich in detail** is the Eur-LFS-SSP5 narrative? To what extent are the **specifics** of the European Livestock Farming Systems addressed in the SSP5 narrative? In your opinion, what other specifics of the European Livestock Farming Systems should be addressed in the SSP5 narrative? Please comment your rating.
1 – not at all rich in detail and not at all addressing specifics, 5 = very rich in detail and addressing specifics

| Rating | Comment Stakeholder | Response Researchers |
|---|---|---|
| 4 | The presented narrative addresses population dynamics, policy shifts towards deregulation, economic growth, market liberalisation, technological advancements, and their consequent impacts on animal welfare, environmental standards, and agricultural practices. However, while the narrative is rich in macro-level details, it could benefit from more granular insights into specific livestock farming practices, regional variations within Europe, and the potential long-term sustainability challenges beyond economic and technological dimensions. Additionally, aspects such as the impact on small-scale farmers, the role of consumer behaviour in shaping industry practices, and the interplay between local and global markets could further enrich the narrative. | We tried to incorporate these aspects to some extent, but not all of them, as the narrative is already rather long. |

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| | | |
|---|---|---|
| 4 | The narrative is well-detailed. It would be beneficial to detail further the impact of the communicable diseases and the reasoning behind its increase. | We provided some more details regarding communicable diseases. |
| 4 | Good level of detail but could address some of the effects of loss of biodiversity not just on communicable zoonotic diseases but on the ability of other resources to support the agriculture i.e. soil health. | We provided some more details regarding the biodiversity loss and communicable diseases, as well as soil health. |
| 4 | The SSP narrative is detailed and provides a clear understanding of the scenario. | |

5) How appropriate is the **title and acronym** for the Eur-LFS-SSP5 narrative? What alternative title or acronym would you suggest?
1 – not at all appropriate, 5 = very appropriate
Eur-LFS-SSP1: European Livestock Farming Systems in a Sustainable Era
Eur-LFS-SSP2: European Livestock Farming in a Conventional Era
Eur-LFS-SSP3: European Livestock Farming in a Food Sovereignty Era
Eur-LFS-SSP4: European Livestock Farming in an Unequal Green Era
Eur-LFS-SSP5: European Livestock Farming in an Innovative Fossil-fuelled Era

| Rating | Comment Stakeholder | Response Researchers |
|---|---|---|
| 4 | I consider the title to be correct. I think the addition of the word "but" is vital to highlight the fact that innovation (in a neoliberal context) is often linked to increased consumption of fossil fuels. | We added But in the title. |
| 5 | Title is OK | |
| 5 | The title is appropriate. | |
| 5 | The title is appropriate | |

6) Additional stakeholder comments in the narrative text.

| Comment Stakeholder | Response Researchers |
|---|---|
| Change the development direction from +1 to -1 for Manure management efficiency, because manure mainly seen as waste. | We changed the development direction according to your suggestion as this is still consistent within the scenario and is also compatible with the scenario logic. We reframed the narrative such that technology rather focuses to ease manure management but does not target efficiency. |

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