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Shared Socio-economic Pathways for European agriculture and food systems: The Eur-Agri-SSPs

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ABSTRACT

Scenarios describe plausible and internally consistent views of the future. They can be used by scientists, policymakers and entrepreneurs to explore the challenges of global environmental change given an appropriate level of spatial and sectoral detail and systematic development. We followed a nine-step protocol to extend and enrich a set of global scenarios – the Shared Socio-economic Pathways (SSPs) – providing regional and sectoral detail for European agriculture and food systems using a one-to-one nesting participatory approach. The resulting five Eur-Agri-SSPs are titled (1) Agriculture on sustainable paths, (2) Agriculture on established paths, (3) Agriculture on separated paths, (4) Agriculture on unequal paths, and (5) Agriculture on high-tech paths. They describe alternative plausible qualitative evolutions of multiple drivers of particular importance and high uncertainty for European agriculture and food systems. The added value of the protocol-based storyline development process lies in the conceptual and methodological transparency and rigor; the stakeholder driven selection of the storyline elements; and consistency checks within and between the storylines. Compared to the global SSPs, the five Eur-Agri-SSPs provide rich thematic and regional details and are thus a solid basis for integrated assessments of agriculture and food systems and their response to future socio-economic and environmental changes.

1. Introduction

Changes in climatic, environmental, socio-economic and technological conditions, whether gradual or abrupt, can be challenging for agricultural and societal systems to deal with, but at the same time may offer new opportunities for enhancing agricultural and food sustainability (e.g., Bebber et al., 2013; Knox et al., 2016; Leclère et al., 2014; Liu et al., 2019; Reich et al., 2018). Future developments that bring

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about such changes are deeply uncertain, but society may be able to manage them better if some plausible developments have already been anticipated. Here, we apply a scenario approach to develop socio-economic storylines describing alternative plausible future pathways for the European agriculture and food systems.

Scenarios can be qualitative storylines (i.e., narratives), quantified descriptions of alternative futures, or anything in between (IPCC, 2014; Reed et al., 2013; Swart et al., 2004). They can be used to describe, explore and communicate how the future may unfold. Starting from a defined initial situation for a specific region and thematic focus, scenarios look into the future by reflecting on an internally consistent set of assumptions about key drivers and their relationships (IPCC, 2014). Most often, a scenario matrix is used to structure future developments along two causally independent drivers, and to provide a basic frame for comparing and contrasting scenarios .

Scenario development has gained in importance over the last decades because of its wide applicability in research and practice. For instance, scenarios can inform integrated assessments of agriculture and food systems (Feusthuber et al., 2017; Harrison et al., 2016; Hauck et al., 2019; Holman et al., 2017; Mitter et al., 2015a; Popp et al., 2017; Schönhart et al., 2018) and can stimulate and guide research, public debate, education and communication (Le Mouël et al., 2018; Öborn et al., 2013; Veland et al., 2018; Vervoort et al., 2010). They can inform strategic planning of private investments or designing of policies (Butler et al., 2016; de Lattre-Gasquet, 2018; Frame et al., 2018; Harrison et al., 2019; Mitter et al., 2015b; Mitter and Schmid, 2019; Rounsevell and Metzger, 2010) and may thus help to steer towards a sustainable and resilient future. To successfully serve these purposes, a transparent and systematic scenario development process is key (Carlsen et al., 2017; Kunseler et al., 2015). Multi-perspective dialogue (Borch and Mérida, 2013) and stakeholder engagement strengthen scenarios to address the expertise and various needs of researchers, policy and decision makers in the public, private and educational sectors. Finally, considering alternative futures makes planning more resilient to unexpected shocks and disruptions.

In climate change research, scenarios are crucial for exchanging information across and within scientific communities (van Vuuren and Carter, 2014), and for comparing research and modeling results across temporal and spatial scales. In recent years, a new global scenarios concept, Shared Socioeconomic Pathways (SSPs, O'Neill et al., 2017, 2014) has been widely adopted by the climate change research community. These characterize five socio-economic pathways that encompass contrasting challenges related to climate change mitigation and adaptation and thus cover a large uncertainty space. The SSPs provide qualitative descriptions as well as model-based quantifications of plausible global developments of socio-economic conditions including population growth, demographic change, urbanization, economic development and technological progress (see Riahi et al., 2017 for an overview of the development of the SSPs and the SSP Database https://tntcat.iiasa.ac.at/SspDb for extended reporting of existing SSP scenarios). O'Neill et al. (2014) and van Ruijven et al. (2014) differentiate between 'basic' and 'extended SSPs'. The former shall provide sufficient information to outline alternative future development pathways, while the latter build on the basic SSPs to ensure consistency between scales or sectors and provide more details for sectoral or regional applications.

Diverse methodological approaches have been applied to develop extended SSPs at the global and regional scales and with different thematic foci and time scales. At the global scale, the Agrimonde-Terra scenarios couple a qualitative approach based on morphological analysis (Ritchey, 2011) and a quantitative modeling approach to explore land use and food security in 2050 (Mora and de Lattre-Gasquet, 2018; Mora et al., 2020). Similarly, Lenzner et al. (2019) propose to combine stakeholder engagement and numerical models to derive scenarios on biological invasions for the 21st century. The diet-SSPs are qualitative storylines that elaborate on food systems for diet, nutrition and health until 2050 (Bodirsky et al., 2019). Participatory approaches have been used to develop long-term global oceanic system pathways (Maury et al., 2017), and mathematical models have been applied to various sectors (e.g., energy and land use) to quantify the development of specific elements of the global SSPs until 2100 (Bauer et al., 2017; Popp et al., 2017; Riahi et al., 2017; van Vuuren et al., 2017).

At regional scales, extensions include qualitative storylines for Europe until 2100 (Eur-SSPs; Kok et al., 2019); Representative Agricultural Pathway narratives (RAPs) for the U.S. dryland wheat-based systems until 2050 (Antle et al., 2017; Mu et al., 2019) and for Kenya until 2030 (Claessens et al., 2012); as well as quantified scenarios on agriculture and food security for West Africa until 2050 (Palazzo et al., 2017). Other examples include those for Europe and Central Asia with a focus on biodiversity and ecosystem services (Harrison et al., 2019), for Europe's urban land use change (Terama et al., 2019), for New Zealand to inform policy and decision making (Frame et al., 2018), for the Barents region (Nilsson et al., 2017) and for the U.S. Southeast for adaptation planning (Absar and Preston, 2015), for the Mediterranean coastal zone with a focus on population projections (Reimann et al., 2018), for the Baltic Sea region and its environmental problems (Zandersen et al., 2019), and for a river delta in China to manage regional water use (Yao et al., 2017). We refer the reader to the ICONICS (International Committee On New Integrated Climate change assessment Scenarios) database for an extensive overview of publications related to the SSP framework and to the SSPs (https://depts.washington.edu/iconics/publications/) as well as to the Foresight4Food International Collaborative Initiative (https://www.foresight4food.net/) and its platform for foresight activities related to agriculture and food systems. These regional extensions have added to the wealth of scenarios and to the methods used to develop them. Yet, conceptual and methodological transparency and rigor lags behind (Carlsen et al., 2017) and scenario development has often been criticized for insufficient scientific neutrality and replicability (Beck and Mahony, 2017; Carlsen et al., 2017) including unsystematic stakeholder selection and engagement (Reed et al., 2013).

We augment the existing set of SSPs by systematically developing five storylines for European agriculture and food systems (Eur-Agri-SSPs) following a detailed and stakeholder inclusive step-by-step protocol (Mitter et al., 2019). The Eur-Agri-SSPs describe alternative plausible future developments for the European agriculture and food systems advanced along the challenges to climate change mitigation and adaptation until 2050. They aim to capture uncertainties in major socio-economic, environmental and technological drivers and include information on population and urbanization, economic development, policies and institutions, environment and natural resources. Such information is useful for researchers performing integrated assessments of climate change challenges in agriculture and food systems at the European scale and under different socio-environmental developments. Furthermore, the Eur-Agri-SSPs may inform public policy and private business decision making.

The article is structured as follows: in Section 2, we describe how the collected data were analyzed by following the nine transparent and stakeholder inclusive working steps of the Mitter et al. (2019) protocol; in Section 3, we provide the main outcomes of the multi-year, participatory scenario development process; in Section 4, we discuss application potentials of the Eur-Agri-SSPs and major challenges encountered in the development process; and in Section 5 we conclude with lessons learned.

2. Material and methods

We develop Eur-Agri-SSPs in order to advance research on European agriculture and food systems in a transparent and systematic way. To extend the basic SSPs, a consecutive, one-to-one nesting approach is chosen, i.e., the finalized basic SSPs set the boundary conditions. In the following, we describe the methods applied to analyze the compiled

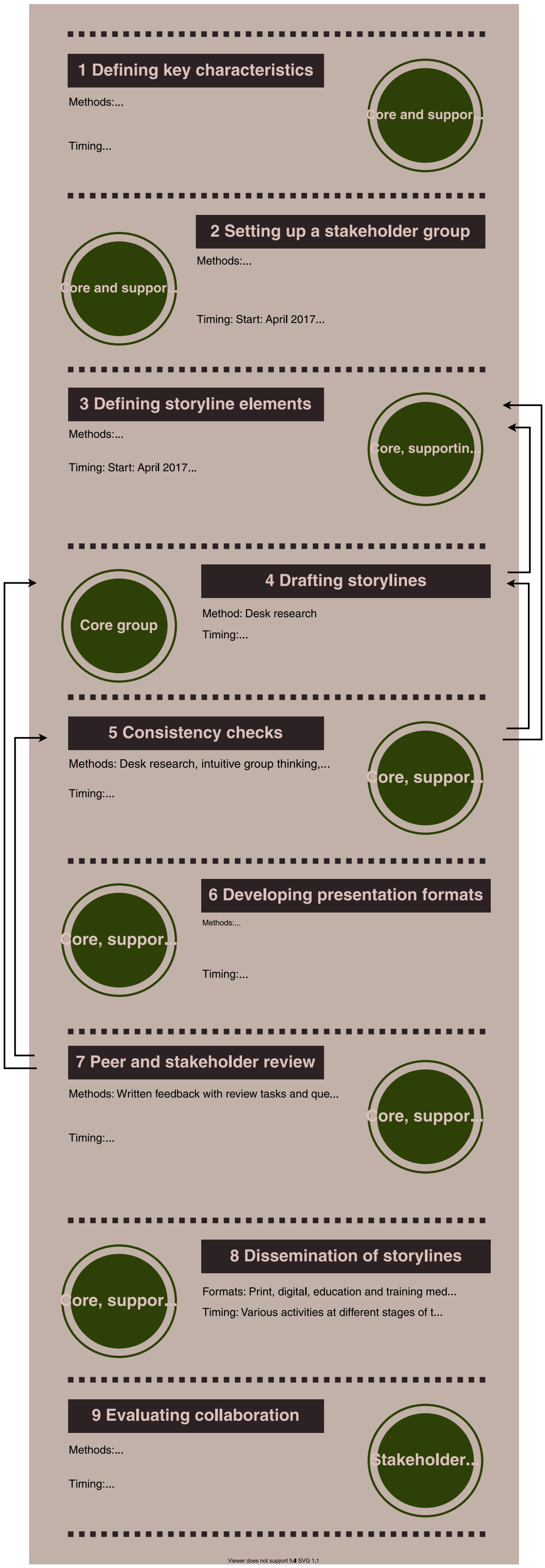

Fig. 1. Overview of the research process based on the nine working steps defined in the protocol by Mitter et al. (2019). *Notes:* For each working step (grey rectangle), the scenario working groups involved (green circles), the applied methods and the timing are given. The arrows indicate that the research process was iterative, i.e., some working steps were repeated until the final Eur-Agri-SSPs were developed. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

data and resources. Additional information and material for specific working steps is provided in the Supplementary Material (SM II).

2.1. Method of analysis

The protocol for developing the Eur-Agri-SSPs transparently defines nine working steps, specifies responsibilities of three multi-disciplinary scenario working groups (i.e., core, supporting, and stakeholder groups), and proposes methods as well as opportunities for stakeholder engagement (Mitter et al., 2019). Fig. 1 summarizes how the protocol was applied to develop the Eur-Agri-SSPs, whereby the arrows indicate the iterative character of the working steps. In our case, the core group comprises six scientists from three European research institutions, and the supporting group is composed of 15 scientists from across Europe. The stakeholder group is represented in the second step of the protocol and respective affiliations are listed in Table SM II.1. Using the protocol enables meeting pre-defined quality criteria such that the storylines are plausible, internally (i.e., horizontally) consistent and consistent across spatial scales (i.e., vertically consistent), salient or relevant for targeted users, legitimate in that they consider diverse interests, rich in detail, and creative or widely diverse.

2.1.1. Defining key characteristics of the storylines

The goal and purpose, target groups, thematic focus, spatial and time scale of the storylines were agreed upon at the beginning of the process in order to guide the storyline development. The core and supporting groups defined these key characteristics of the Eur-Agri-SSPs in moderated group discussions. The virtual and face-to-face discussions were supplemented by personal and digital exchanges regarding specific topics.

2.1.2. Setting up a stakeholder group

Engaging a broad variety of stakeholders in a storyline development process can increase creativity, salience, richness, and horizontal consistency (Alcamo et al., 2008). Furthermore, it may reduce unintended bias from diverse personal backgrounds, interests and professional knowledge (Ernst et al., 2018). Accordingly, the main criteria for stakeholder identification and selection defined by the core group were to cover a wide spectrum of knowledge types, roles in policy and decision making at the European and national scales, topical expertise, academic and non-academic backgrounds, geographic diversity, cultures, gender and age. Diversity was achieved by including people from the public and private sectors, academia, advocacy groups and associations as well as inter-governmental and non-profit organizations working at European and national scales. The core and supporting group members performed a literature and online search for relevant stakeholders and reached out to their professional networks. In addition, the identified stakeholders suggested contacts to other relevant or potentially interested persons (snowball sampling approach).

2.1.3. Defining storyline elements

The storylines should address clearly defined elements that are particularly relevant and uncertain (Alcamo and Henrichs, 2008) for the future development of the European agriculture and food systems. The core and supporting groups applied different methods to identify, cluster and prioritize storyline elements. The core group conducted a literature review in order to specify the boundary conditions set by the basic SSPs and the Eur-SSPs to determine the central elements of agriculture and food systems and to prepare subsequent stakeholder interactions. Stakeholder engagement is key in this working step because it stimulates discussions and encourages non-linear and out-of-the-box thinking. Stakeholders were engaged in three workshops organized by the core group and via semi-structured interviews conducted by the members of the core and supporting groups. Stakeholders were asked to describe drivers of future development in the agriculture and food systems, to rank these drivers by importance and uncertainty, and to estimate plausible directions of change over the next three decades, including 'extreme' developments and 'surprising' outcomes in order to derive a gradient of expressions for each driver (Wright et al., 2013).

The core group was responsible for analyzing the qualitative data compiled during the workshops and semi-structured interviews, clustering the storyline elements, and summarizing potential directions of change. Data analysis was supported by the qualitative data analysis tool Atlas.ti. A prioritization for the storyline elements was guided by the objective to avoid potential conflicts with other spatial and (sub-) sectoral storyline extensions as well as with quantitative model outputs. Guidance for differentiating between typical inputs and outputs of agriculture and food systems models was provided by the core and supporting group members' expertise and from the literature.

2.1.4. Drafting storylines

The core group drafted the Eur-Agri-SSPs by linking the identified directions of change from each storyline element under the framework of the SSPs. While the stakeholders were explicitly asked for socio-economic, environmental and technological drivers of European agriculture and food systems until 2050 and the ranges of change for the drivers, the core group's task was to combine the storyline elements and determine the directions of change for each element and Eur-Agri-SSP. Similar to many previous scenario exercises (Abildtrup et al., 2006; Absar and Preston, 2015; Antle et al., 2017; Busch, 2006; Palazzo et al., 2017; Reimann et al., 2018; Valdivia et al., 2015; Vervoort et al., 2014), we differentiate increasing, decreasing and stable developments, compared to the initial conditions in the starting year. This implies that directions of change for individual storyline elements can be the same for two or more storylines even if the underlying development patterns differ. The core and supporting groups agreed on the directions of change in an iterative process. Related storyline elements were identified in causal loop diagrams (Mathijs et al., 2018) and the core group established development paths for each storyline, based on the SSPs (narratives and quantifications), alternative scenarios for agriculture and food systems, and theoretical considerations. Changes proposed by the supporting group members were considered if their argumentation was considered theoretically consistent and reasonable.

2.1.5. Consistency checks

Consistency checks are important in order to increase robustness (Priess and Hauck, 2014; Priess et al., 2018) because larger scale storylines set boundary conditions for smaller scale storylines (Zurek and Henrichs, 2007) and individual storyline elements influence each other (Schweizer and O'Neill, 2014). We differentiate between vertical (with the global SSPs) and horizontal consistency (internal or self-consistency; Weimer-Jehle, 2006). While the core and supporting groups reviewed both vertical and horizontal consistency, stakeholders were asked to focus on horizontal consistency according to their specific expertise. Systematic consistency checks required three iterative working steps. First, each Eur-Agri-SSP was cross-checked on the respective SSP narrative and related quantified storyline elements for vertical consistency. Second, scientific theory (e.g., economic and behavioral theory), causal loop diagrams (Mathijs et al., 2018) and intuitive logics (Bradfield et al., 2005; Wright et al., 2013) helped to understand causal processes, to identify relationships between storyline elements and to achieve horizontal consistency. Experiences of agriculture and food systems modeling from the supporting group supported this step. Third, the Eur-Agri-SSPs were compared against each other to ensure contrasts while maintaining consistency. Consistency checks were repeated several times and partly combined with peer and stakeholder reviews (Section 2.1.7). The core group updated the draft storylines if causality was not entirely clear or deviated from established scientific theories. Contradictory comments were resolved in the core group via majority decisions.

2.1.6. Developing presentation formats

The core group developed visual and tabular presentation formats of the Eur-Agri-SSPs to communicate the results to the supporting group and obtain feedback, as well as to increase their effectiveness for stakeholders for decision making purposes (Padilla et al., 2018; Tufte, 1998). The tables provide a hierarchically structured overview of the storyline elements, i.e., each element is attributed to a topic. During a workshop, stakeholders were invited to reflect on the titles and pictures they had in mind for specific storylines in a stimulating environment. Based on the collected ideas, three sets of titles were developed and the supporting group members agreed on one set by a majority vote. Furthermore, the core group established the website https://eur-agri-ssps.boku.ac.at as a platform for sharing information, communication, education and interaction, and to serve as a freely accessible forum for the storylines to be openly discussed and commented.

2.1.7. Peer and stakeholder review and revision of storylines

The core, supporting and stakeholder groups were involved in the review and revision processes which focused on the quality criteria as defined in the protocol, i.e., plausibility, consistency, salience, legitimacy, richness and creativity (Mitter et al., 2019). Overlaps between the broad review process and the more focused consistency checks arose (Section 2.1.5). Four major review and revision rounds were necessary until no new comments came up and agreement on the final storylines could be achieved. The first storyline drafts were reviewed with written feedback by the core and supporting groups. According to the quality criteria, we specified six review tasks, ensuring that each task was covered by several group members. The revised version was discussed by the supporting and stakeholder groups in a two-day workshop. The workshop participants were purposefully assigned to review groups. Each group evaluated one storyline by answering six questions referring to the quality criteria. In addition to the moderated group discussions, review sheets were distributed during the workshop and the participants were invited to write down their feedback. In the third revision round, the core and selected supporting group members provided written and oral feedback with a particular focus on clarity, comprehensibility and consistency. The feedback was incorporated into the storylines, and the draft Eur-Agri-SSPs (including their summaries) were distributed amongst the core, supporting and stakeholder groups for a final revision.

2.1.8. Dissemination of storylines

Effective communication and different forms of dissemination for the storylines are important in order to reach potential users (van Vuuren et al., 2012) and to make the storylines accessible to researchers, policy and decision makers, students and the interested public with varying (cross-) sectoral and (cross-) scale interests and perspectives. The core, supporting and stakeholder groups were involved in this step to increase the diversity of information, communication and dissemination channels. While the core group developed various dissemination formats, the supporting and stakeholder groups provided comments and feedback to increase the usefulness of the products. Dissemination formats and channels were customized to the targeted users and to the purpose of the dissemination activity.

2.1.9. Evaluating collaboration for storyline development

Evaluation is crucial to allow for methodological improvements and interpretation of scenario process and products. Feedback on the storyline development process was collected after formal interactions with stakeholders in order to improve working relationships, increase productivity and enhance performance (see Priess et al., 2018). The evaluation methods were adjusted to the Eur-Agri-SSP setting, e.g., rating questions related to the content, targets, methods and interaction during workshops or stakeholder engagement in developing Eur-Agri-SSPs in general.

2.2. Data and resources

The development of the Eur-Agri-SSPs was informed by the basic SSPs and other scenario related exercises as well as by knowledge, expertise and expectations of a diverse group of researchers and stakeholders.

The SSP literature was reviewed to specify boundary conditions for the Eur-Agri-SSPs. Major topics (e.g., demographics) and individual storyline elements (e.g., population size) were listed and storyline elements with similar meanings were summarized with one term. The major topics and storyline elements served as a starting point for analyzing the semi-structured stakeholder interviews, which may be interpreted as a deductive approach. Future dynamics and development paths of selected storyline elements have also been based on the SSPs, i.e., narratives and quantifications of plausible developments. In addition to the SSPs, recently published scenarios related to agriculture and food systems and with a time horizon similar to the Eur-Agri-SSPs were identified. The major purpose of scanning scenario exercises was to check for potential overlaps (e.g., storyline elements) and to build on existing knowledge of causalities and the exploration of trends. Grey literature from relevant European and national organizations and institutions that provide future visions of agriculture and food systems and related sectors was primarily used to prepare subsequent stakeholder engagement activities. Relevant sources and projects consulted in this research step are listed in Table 1.

Stakeholders provided fresh inputs and creative ideas regarding potential future developments. Stakeholder engagement was dynamic and depended on the aim of the respective working step and therefore it varied over time. Qualitative data were a major input for specifying the storyline elements and development paths that are characteristic of the agriculture and food systems. In total, 105 individuals from 60 national and European organizations and institutions contributed to the Eur-Agri-SSPs with their knowledge, expertise and expectations (Table SM II.1). Data collection was organized through four workshops and 50 semi-structured interviews. The aims of the activities are briefly described and the core workshop and interview material is available in SM II.

3. Results

The Eur-Agri-SSPs were developed using an iterative and participatory process. Below we present major final outputs from the multi-year process. We refer the reader to SM II for intermediate steps and results that highlight consensus and controversies.

3.1. Key characteristics of the Eur-Agri-SSPs

The major purpose of this scenario exercise was to develop five sector-specific socio-economic storylines for Europe that capture the uncertainties related to the challenges to climate change mitigation and adaptation. The problem-focused storylines aim to describe alternative plausible pathways for the European agriculture and food systems until 2050. Potential users of the storylines are researchers working on climate change in agriculture and food systems as well as policy and decision makers from the public and private sectors. These framing conditions determine the key characteristics of the Eur-Agri-SSPs as summarized in Table 2.

3.2. Eur-Agri-SSPs

The Eur-Agri-SSPs describe plausible changes in key socio-economic, environmental and technological drivers that affect climate change mitigation or adaptation options as well as sustainability levels in European agriculture and food systems. They bundle the diverse perspectives of different stakeholders into internally consistent development pathways, the effects of which (e.g., on land use change) can then be modeled quantitatively. They do not provide national details, nor development trajectories in related sectors, such as forestry.

The Eur-Agri-SSPs extend and enrich the basic SSPs with a regional and sectoral component and mirror the structure of the SSPs for reasons of vertical consistency (Fig. 2). The storylines touch upon five major topics: population and urbanization; economy; policies and institutions; technology; environment and natural resources. Summaries of the storylines are presented below. The comprehensive storylines are provided in SM I.

3.2.1. Eur-Agri-SSP1 – Agriculture on sustainable paths (see SM I.1 for comprehensive storyline)

In Europe, social and environmental awareness increase steadily and significantly and are reflected by increasingly effective cooperation between public and private sectors and civil society. This is accompanied by tightened pro-environmental policies; abolished income support for farmers; rising public payments for the provision of regulation and cultural services; taxes on environmental damages; decreasing resource depletion; and technology developments towards low emissions, resource use efficiency and chemical pesticide-free agriculture. European domestic demand shifts towards plant-based diets

Table 1
Reviewed literature that informed the development of the Eur-Agri-SSPs.

SSP related literature at global and regional scales	
Global	Bodirsky et al., 2019; Dellink et al., 2017; Jiang and O'Neill, 2017; Samir and Lutz, 2017; Kriegler et al., 2012; O'Neill et al., 2017, 2014
Regional	Absar and Preston, 2015; Kok et al., 2019, 2015
Projects on alternative scenario exercises	
AgMIP/RAPs	Valdivia et al., 2015
Agrimonde-Terra foresight	Le Mouël et al., 2018
CLIMSAVE and IMPRESSIONS	Gramberger et al., 2011; Harrison et al., 2013; Holman et al., 2017; Kok et al., 2015; Kok and Pedde, 2016
Global Europe	European Commission, 2011
OpenNESS	Hauck et al., 2017, 2015; Priess et al., 2018
SUREFarm	Mathijs et al., 2018
TRANSMANGO	Vervoort et al., 2016
Additional information	
European agriculture and food systems	Bergez et al., 2011; Mylona et al., 2016; Öborn et al., 2013; Vervoort et al., 2014
Agriculture and food systems models	Janssen et al., 2017; Jones et al., 2017; Reidsma et al., 2018

Table 2
Key characteristics of the Eur-Agri-SSPs defined by the core and supporting groups.

Key characteristics	Specification for Eur-Agri-SSPs
Goal and purpose	Extend and enrich the SSPs by providing a regional (Europe) and a sectoral component (agriculture and food) in a systematic way Provide a set of alternative future developments of the European agriculture and food systems Provide a set of plausible storylines capturing future key uncertainties Provide a solid basis for integrated assessments of agriculture and food systems to increase comparability of their results Stimulate discussion between various actors with different interests, backgrounds and professional activities
Main target groups	Scientists from the climate change, agricultural, food and integrated assessment research communities working at European to national scales Policy makers in European agriculture and food systems Decision makers in the private sector (e.g., supply chain managers)
Thematic focus	Describe worlds in which socio-economic, environmental and technological drivers make it harder or easier to mitigate or adapt to climate change in agriculture and food systems or to tackle other sustainability issues
Spatial scale	Europe, with differentiations between nations or agri-environmental zones kept to a minimum
Time scale	2050 with optional extension to 2100
Scenario type	Qualitative storylines, semi-quantitative specifications of trends, problem-focused
Quality criteria	Plausibility, consistency (vertical and horizontal), salience, legitimacy, richness, creativity

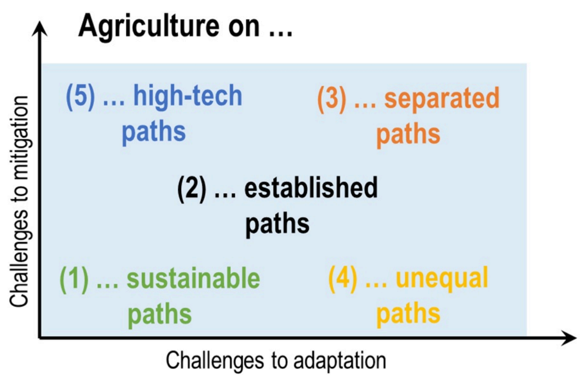

Fig. 2. The Eur-Agri-SSPs (based on O'Neill et al., 2017, 2014).

and bio-based materials, whereas food waste and per capita demand for livestock-based products decrease gradually. Markets are globally connected and trade agreements are strengthened. International trade decreases because short and transparent agricultural supply chains are preferred by consumers and external costs, e.g., for transportation, are internalized in agricultural commodity prices. Challenges to climate change mitigation are low in the agriculture and food systems because of a decreasing demand for livestock-based products and technology development with a focus on reducing greenhouse gas emissions. Challenges to climate change adaptation are also low because of increasing institutional effectiveness focusing on support for sustainable farming, public investments in infrastructure development, and cooperation along the agricultural supply chain.

3.2.2. Eur-Agri-SSP2 – Agriculture on established paths (see SM I.2 for comprehensive storyline)

European development follows historical patterns resulting in slow but steady social, environmental and technological progress. Cooperation between public and private sectors remains challenging with little progress in implementing further environmental standards and policy instruments. European agricultural policy is characterized by multiple support schemes to increase international competitiveness, productivity and efficiency, and improve environmental status. National policies complement the European policy framework. Agricultural commodities are mostly traded within Europe even though global market integration advances. Demand for locally produced food, bio-based materials, regulation services and landscape amenities increases slowly, whereas per capita meat demand remains high. Depletion of natural resources increases because of continuous growth of the agriculture and food economy, and pro-environmental regulations and resource-efficient technologies are only developed at a moderate pace. Challenges to climate change mitigation are moderate because agriculture and food systems partly remain dependent on fossil energy sources, resource-efficient technology development is advancing gradually but is not expedited, and pro-environmental policy instruments remain inefficient. Challenges to climate change adaptation in agriculture are moderate because of slow and insufficient development of European agricultural policy, and reduced investments in infrastructure in rural areas.

3.2.3. Eur-Agri-SSP3 – Agriculture on separated paths (see SM I.3 for comprehensive storyline)

Mutual distrust and regional rivalry result in less efficient cooperation between national and European entities, more severe European and international trade restrictions, the emergence of national agricultural policies, and relaxed environmental standards. Increased self-sufficiency concerns of individual countries influence demand patterns for food, feed and agro-fuels. Public payments aim to maintain the national production potential, whereas demand for environmental services declines. Access to international markets decreases, whereas neo-colonialism and land grabbing gain in importance. Market concentration increases within countries and national governments keep agricultural production standards low. Technology development and diffusion suffer from declining public and private investments and weak cooperation between governments and actors in the agricultural supply chains. Challenges to climate change mitigation are high because of a lack of cooperation between the public and private sectors, decreasing environmental awareness, reduced public payments for environmental services, and slow technological progress that focuses on productivity instead of greenhouse gas emission reduction targets. Challenges to climate change adaptation are high due to a combination of decreasing institutional effectiveness, reduced diffusion of new technologies between nations, tighter budget constraints, a dominance of national agricultural policies, and decreasing investments in infrastructure in urban and rural areas.

3.2.4. Eur-Agri-SSP4 – Agriculture on unequal paths (see SM I.4 for comprehensive storyline)

Increasing social disparities between and within rural and urban areas lead to social segregation. A business-oriented, wealthy upper class dominates European institutions, sets the policy agenda, controls agricultural supply chains, and stimulates technological uptake of energy efficient and renewable energy technologies, whereas the lower class majority are poorly represented in European institutions and agricultural supply chains. European agricultural policies increasingly support economic growth and technology development, from which the large, industrialized farms benefit the most and the interests of a large proportion of society are mostly ignored. Agricultural markets are increasingly globally connected and demand for European agro-food products is increasingly diverse, with a stagnation in domestic demand for feed and non-food commodities. Environmental standards decrease except for selected, scenic, hot spot regions. Natural resources are increasingly overused. Challenges to climate change mitigation are low in the agriculture and food systems because of effective European institutions, progress in technology development (towards low emissions and nitrogen efficiency), and rising public payments for technology penetration. Challenges to climate change adaptation are high because of growing inequalities in access to institutions and production-related support, to globally connected markets, and to education.

3.2.5. Eur-Agri-SSP5 – Agriculture on high-tech paths (see SM I.5 for comprehensive storyline)

European residents share a growing faith in technology, material-intensive lifestyles and trade liberalization, which is reflected by improved international trade agreements, globally connected agricultural supply chains, accelerated technological progress and diffusion in the agriculture and food systems, and expedited structural change. Individuals' affinity for technological innovation also affects increasing global demands for European agricultural products, particularly for bio-based industrial raw materials as well as bio-based and innovative products. Increased private investments in technological know-how and the education of employees in the agriculture and food systems boost economic growth, which is largely dependent on fossil energy sources. Public payments to the agriculture and food systems are drastically reduced to conform with liberalized and integrated markets. Environmental standards are considerably lowered, which results in overexploitation of natural resources in Europe and abroad. Challenges to climate change mitigation are high in the agriculture and food systems mostly because of decreasing environmental awareness, massively reduced payments for environmental services, and a growing reliance on fossil energy sources and other fossil-based inputs. Challenges to climate change adaptation are low because of increasing investments in social and technical infrastructure, higher economic growth rates and professionalization in the agriculture and food systems.

3.3. Storyline elements

The storyline elements form an important basis for developing the comprehensive Eur-Agri-SSPs. Table 3 gives an overview of the storyline elements and summarizes the directions of change for the five Eur-Agri-SSPs. It is structured around the five major topics population and urbanization; economy; policies and institutions; technology; environment and natural resources.

4. Discussion

We developed five semi-quantitative scenarios for the European agriculture and food systems, called the Eur-Agri-SSPs and extended the basic SSPs in a structured and participatory process. However, we also experienced several challenges during the storyline development process and recognized limitations of the storylines. In this section, we first highlight application potentials of the Eur-Agri-SSPs and then discuss experienced challenges clustered around five major topics, (i) extension of the basic SSPs, (ii) participatory storyline development, (iii) interdisciplinary cooperation for storyline development, (iv) consecutive, one-to-one nesting approach, and (v) science-driven storyline development. Where appropriate, we refer to the related quality criteria of plausibility, consistency, salience, legitimacy, richness and creativity as defined in Mitter et al. (2019). In SM II, we provide additional material and intermediate results in order to increase process transparency.

4.1. Application potentials of the Eur-Agri-SSPs

Based on the feedback from the core, supporting and stakeholder groups, we have identified four major fields of application of the Eur-Agri-SSPs, i.e., research, policy design and implementation, private decision making, and education. Scientists have a strong interest to use the storylines as an input for integrated assessments of agriculture and food systems at the European scale (e.g., to inform modeling assumptions) and to expand the storylines for regional or sub-sectoral applications (e.g., Kampermann, 2019). As such, the storyline development process has already affected the research design of on-going projects (e.g., the BonaRes, DAKIS, SALBES, and SureFarm research projects). Furthermore, the Eur-Agri-SSPs can stimulate new research, and can serve as a reference for further scenario and strategic foresight studies as well as for the design of research programs, such as Horizon Europe, the next research and innovation framework program of the European Commission, starting in 2021. With respect to policy design and implementation, the stakeholder group highlighted the Eur-Agri-SSPs as a potential planning tool for policies, especially in the context of rural and agriculturally dominated areas, nature-based solutions, land management, ecosystem services, bio-economy, international trade and the European Single Market as well as the Sustainable Development Goals. Furthermore, members from the stakeholder group referred to the usefulness of the storylines for explaining the role of the Common Agricultural Policy, for comparing and informing national agricultural strategies, and for focusing ideas on historical and preferable future developments in agriculture and food systems. The Eur-Agri-SSPs may inform the strategic orientation of private companies and may thus inform decision making. In education, the storyline development process is considered suitable for introducing students to foresight and scenario approaches. The storylines can be used to stimulate students' discussions on different, plausible futures.

4.2. Extension of the basic, global SSPs

The basic, global SSPs served as a starting point for developing the Eur-Agri-SSPs. This basis was enriched by the Eur-SSPs, which are equivalent to the global SSPs and thus provide a regional interpretation. We summarize similarities and differences between the basic, global SSPs, the Eur-SSPs and the Eur-Agri-SSPs in Table 4. The applied SSP framework, which highlights challenges to climate change mitigation and adaptation, as well as SSP elements clearly influenced the specification of the Eur-Agri-SSPs. However, differences emerged mostly because of the stakeholder engagement. For instance, the stakeholders emphasized the importance of future developments of the agriculture and food markets and of European agriculture, food and environmental policies. The economy, policies and institutions are thus given more weight in the Eur-Agri-SSPs, compared to the basic SSPs. Stakeholders also articulated the risk of a scenario with 'medium' change, that is most often preferred by decision makers and represented by the SSP2 pathway, because potential for changes would be ignored. Some even recommended to skip developing a Eur-Agri-SSP2 altogether. However, the core and supporting groups decided to deviate from the basic SSP2 pathway to develop selected agriculture-specific storyline elements that were defined as 'increasing' or 'decreasing' in the Eur-Agri-SSPs, compared to the 'medium' changes of most storyline elements in the basic SSP2. While vertical consistency was not jeopardized, this deviation increases the attractiveness of the Eur-Agri-SSP2 (Agriculture on established paths) for stakeholders and at the same time enabled it to be modeled quantitatively in the scenario set.

4.3. Participatory storyline development

We have devoted considerable effort to stakeholder engagement during the storyline development process in order to acknowledge heterogeneous perspectives (i.e., legitimacy) and increase the comprehensiveness (i.e., richness), which are documented in SM II. However, some challenges remain which could – to an extent – limit legitimacy, consistency and creativity of the storylines.

First, the full range of actor perspectives in agriculture and food systems has most likely not been considered. Even though we carefully

Table 3
Storyline elements and directions of change for the five Eur-Agri-SSPs.

1 Population and urbanization	Eur-Agri-SSP1	Eur-Agri-SSP2	Eur-Agri-SSP3	Eur-Agri-SSP4	Eur-Agri-SSP5
Population size* (Samir and Lutz, 2017)	→	→	↘	→	↗
Percentage of people living in urban areas* (Jiang and O'Neill, 2017)	↗	↗	↗	↗	↗
Pace of urbanization* (Jiang and O'Neill, 2017)	↗	→	↘	→	↗
Infrastructure development in rural areas	→	↘	↘	↘	→
Urban-rural linkages	↗	→	↘	↘	↘
Levels of social tension and conflict	↘	→	↗	↗	↘
Environmental awareness of citizens	↗	↗	↘	↘	↘
Average educational level of society* (Samir and Lutz, 2017,)	↗	↗	→	→	↗
Individual farmers' social status in society	↗	→	→	→	→
Average age of farming population	↘	→	→	→	↘
Average educational level of the farming population	↗	↗	→	→	↗
2 Economy	**Eur-Agri-SSP1**	**Eur-Agri-SSP2**	**Eur-Agri-SSP3**	**Eur-Agri-SSP4**	**Eur-Agri-SSP5**
Economic model					
Market integration	→	↗	↘	↗	↗
Market concentration in the up- and downstream sector	↘	↗	↗	↗	↗
Economic growth rate (GDP-PPP, based on data extracted from the SSP Database; Dellink et al., 2017)	→	→	↘	→	↗
International trade and global markets					
European trade of agricultural inputs	↘	→	↘	↗	↗
European import of agricultural commodities	↘	→	↘	↗	↗
European export of agricultural commodities	↘	→	↘	↗	↗
Diversity of agricultural supply chains	↗	↘	↘	↘	↘
Pace of structural change in agriculture	→	↗	→	↗	↗
Domestic demand patterns					
Demand for non-food agricultural commodities	→	↗	↗	→	↗
Meat demand per capita (following diet-SSPs; Bodirsky et al., 2019)	↘	→	→	→	→
Demand for feed	↘	→	→	→	→
Demand for regulation and cultural services from the agricultural sector	↗	↗	↘	↘	→
Amount of food waste per capita	↘	→	→	↘	→
Costs, employment and prices					
Relative prices for agricultural inputs	↗	→	↗	↗	↘
Relative prices for natural resources	↗	↗	↗	↗	↗
Labor supply in agriculture	→	→	↘	→	↗
Required skills and knowledge of agricultural labor	↗	↗	→	→	↗
Labor productivity	↗	↗	→	↗	↗
Land productivity	↗	→	→	↗	↗
Relative prices of agricultural commodities	↗	→	↗	→	→
3 Policies and institutions	**Eur-Agri-SSP1**	**Eur-Agri-SSP2**	**Eur-Agri-SSP3**	**Eur-Agri-SSP4**	**Eur-Agri-SSP5**
Political stability	↗	→	↘	↘	↗
Effectiveness of European institutions	↗	→	↘	↗	↗
Multilevel cooperation	↗	→	↘	↗	↗
Societal participation* (O'Neill et al., 2017)	↗	→	↘	↘	↗
International trade agreements	↗	↗	↘	↗	↗
Relative importance of European agri-food policy	↗	↗	↘	→	↘
Socio-environmental focus of agri-food policies	↗	↗	↘	→	→
Environmental standards	↗	↗	↘	↘	↘
Food standards	↗	↗	→	→	↗
Direct payments	↘	→	↗	→	↘
Agri-environmental payments	↗	→	↘	↘	↘
Public payments for rural development and less-favored areas	→	→	↘	↘	↘
Public payments for investments or technology development	↗	→	↘	↗	↘
4 Technology	**Eur-Agri-SSP1**	**Eur-Agri-SSP2**	**Eur-Agri-SSP3**	**Eur-Agri-SSP4**	**Eur-Agri-SSP5**
Speed of agricultural technology development	↗	→	↘	↗	↗
Technology uptake in agriculture	↗	↗	↘	↗	↗
Technology acceptance by producers and consumers	↗	↗	↘	→	↗
5 Environment and natural resources	**Eur-Agri-SSP1**	**Eur-Agri-SSP2**	**Eur-Agri-SSP3**	**Eur-Agri-SSP4**	**Eur-Agri-SSP5**
Resource depletion	↘	↗	↗	↗	↗
Resource use efficiency	↗	↗	↘	↗	→
Occurrence of invasive species	↘	↗	→	↗	↗

Note: *Similar storyline elements have been chosen for the global SSPs (O'Neill et al., 2017) or the Eur-SSPs (Kok et al., 2019). Arrows indicate directions of change, compared to the initial situation at a certain point in time, i.e., increasing (↗), stable (→), and decreasing (↘) developments.

Table 4
Relations between the basic, global SSPs, the Eur-SSPs, and the Eur-Agri-SSPs.

Aspect	Global SSPs[1]	Eur-SSPs[2]	Eur-Agri-SSPs
Description	Pathways (proto-scenarios)	Scenarios	Scenarios
Purpose	To be extended and used and thus to be transformed to full scenarios (SSP scenarios)	To be extended and further downscaled	A set of scenarios that can directly be used
Process	Developed by global climate change researchers	Developed by an interdisciplinary team of European scientists	Co-developed by an interdisciplinary, agriculture-focused team of European scientists and stakeholders
Starting point	Replacing IPCC SRES[3]	Global SSPs, CLIMSAVE and IMPRESSIONS scenarios[4]	Global SSPs and Eur-SSPs
Stakeholder engagement	Limited	CLIMSAVE scenarios were stakeholder driven	Stakeholder driven
Level of detail in storylines	Low to allow extensions	Medium to allow extensions	High sectoral detail to be useful for direct use European focus to allow for spatial extensions
Initial focus	Population and GDP quantifications to support IAM modelers[5]	Storylines to allow downscaling to regional case studies	Storylines and semi-quantitative specifications of trends to allow use in integrated assessments of agriculture and food systems
Overall degree of similarity with global SSPs	–	High, designed to be equivalent Similarity between all main drivers GDP and population were taken from SSP database.	High, but with specific differences because of stakeholder interventions
Specific differences	–	None	General focus on economy as well as policies and institutions Deviations in Eur-Agri-SSP2 from 'medium' changes, where appropriate

Note: IAM (integrated assessment model), IPCC SRES (Intergovernmental Panel on Climate Change, Special Report on Emission Scenarios), GDP (gross domestic product). Key references: [1]O'Neill et al., 2017; [2]Kok et al., 2019; [3]Nakicenovic et al., 2000; [4]Gramberger et al., 2011; Kok et al., 2015; Kok and Pedde, 2016, [5]Riahi et al., 2017.

selected and invited a diverse group of stakeholders to engage in this exercise, we recognize that the perspectives of those who lacked the resources, or who were unwilling to participate in the multi-step process are missing. Similarly, Flick (2009) points out that 'good' co-operative stakeholders do not only possess the necessary knowledge and expertise, but are also capable of reflecting and articulating their perspectives, and can take the time to engage. We experienced a particular challenge in engaging stakeholders from organizations and institutions in East European countries (see Table SM II.1). However, about one third of the involved organizations and institutions represent European interests and employ people originating from across Europe.

Representatives of some companies may not be willing to discuss plans on future developments very openly with policy-makers, their competitors or clients. We have combined individual and group interactions in order to elicit stakeholders' long-term views on future developments, including sensitive topics. Moreover, we have treated stakeholders' contributions as neutrally as possible in order to balance the dominant views and achieve a broad acceptance of the storylines by considering a plurality of futures. While open and unbiased interviews and workshop discussions were encouraged through the choice of neutral venues and the engagement of responsible scientists, professional facilitation of our meetings (with a particularly diverse and large audience) could have strengthened the coordination and alignment of actors' input in various future contexts. The requirement for non-judgmental scientists who are able to switch between reflection, facilitation and intermediation has been highlighted in the process of participatory backcasting (Sandström et al., 2016) and sustainability research (Pohl et al., 2010).

Second, interdisciplinary and participatory storyline development is often related to the 'intuitive logics model' (Bradfield et al., 2005) which is widely applied (Rounsevell and Metzger, 2010) to analyze relationships between critical uncertainties, predetermined trends, and the behavior of actors (Wright et al., 2013), but is criticized for its limited transparency and reproducibility (Carlsen et al., 2017). We have followed suggestions by Wright et al. (2013) for structuring and documenting the stakeholder interviews in order to augment the intuitive logics model and to ensure that major conclusions are robust and independent of the scientists and stakeholders involved. However, this process implicates normative judgements of scientists and stakeholders alike, meaning that another initiative to extend the SSPs for European agriculture and food systems would likely result in different details within the storylines. However, major pathways and storyline elements would likely not deviate strongly due to the boundary conditions set by the SSPs (vertical consistency) and the targeted horizontal consistency.

Third, and similar to Frame et al. (2018) and Kunseler et al. (2015), we faced challenges to reconcile the abundance of stakeholder contributions on storyline elements and potential directions of change that did not always align. Furthermore, stakeholders tended to address specific aspects of single storylines and found it more difficult to respond to the larger picture. Rounsevell and Metzger (2010) argue that differences in epistemologies or knowledge systems and incomplete mental models of the system in question may result in such conflicting stakeholder perceptions. Even though we confronted the stakeholders with the SSP logic and the main ideas of each SSP, incomplete knowledge of the SSPs further complicates stakeholders' inputs. We have based the storyline assumptions on scientific theory and have used causal loop diagrams (Mathijs et al., 2018 and Fig. SM II.9) in order to handle stakeholders' conflicting perceptions on future development. Furthermore, we have distributed the previous versions of the Eur-Agri-SSPs, including summaries, to the supporting and stakeholder groups for feedback in order to achieve agreement on the final version (see SM II). Well-informed key stakeholders were able to identify caveats, logical flaws and weak points in the storylines which were clarified in a revision round in order to increase the usability of the final set of storylines.

4.4. Interdisciplinary cooperation for storyline development

Cooperation among scientists with complementary disciplinary backgrounds, in-depth methodological knowledge as well as inter- and trans-disciplinary expertise proved to be vital for systematic and scientifically credible storyline development, in particular for describing the agriculture and food systems and how they may develop under various future contexts. Despite any formal agreement, our cooperation was effective throughout the storyline development process, which is mostly due to the common interest of the engaged scientists in the application of the Eur-Agri-SSPs for European modeling activities, regional or sub-sectoral extensions. Strong leadership and continuous exchange of information are also of high relevance to keep an informal research consortium active. However, the iterative development of the storylines also required repeated review tasks in order to ensure their plausibility, richness, consistency and salience, which tied up resources.

4.5. Consecutive, one-to-one nesting approach

Developing storylines that are vertically (i.e., with the global SSPs) and horizontally (i.e., internally) consistent is key, but is also a considerable challenge. We have followed a consecutive, one-to-one nesting approach in order to ensure high vertical consistency and to limit the storylines to a manageable number (Absar and Preston, 2015; Zurek and Henrichs, 2007). With consecutive development and one-to-one nesting, the SSPs serve as a starting point and represent boundary conditions for the Eur-Agri-SSPs. However, applying the SSP logic and storyline elements to European agriculture and food systems also implies disadvantages for creativity and salience. Previous exercises on participatory, nested storyline development confirm that stakeholders feel constrained by the framing conditions of storylines from predefined larger spatial scales (e.g., Hagemann et al., 2019).

The consecutive, one-to-one nesting approach implicitly ensures that the European agriculture and food systems evolve in concert with global trajectories and that each global SSP manifests itself into a single Eur-Agri-SSP. This link affects the definition of storyline elements as well as the narrative logic. It constrains potential future developments and may thus discourage visionary thinking. However, the stakeholders were satisfied with the room to maneuver offered by the SSP framework and only mentioned limited room for creativity in the context of Eur-Agri-SSP2 (Agriculture on established paths). In any case, unexpected shocks and disruptions to the agriculture and food systems, such as the exceptional increase in oil prices on the eve of the 2008 financial crisis or the outbreak of the Covid-19 pandemic in 2019/2020 remain largely unreflected in the approach. Such events are often referred to as ‘wild cards’ or ‘surprises’ in the foresight literature (van Notten et al., 2005) and could occur under any of the Eur-Agri-SSPs. However, the consistent integration of the systems’ key drivers can substantially facilitate the analysis of possible long term effects of such external shocks and disruptions.

Potential users’ interests may diverge from the SSP rationale, which may weaken the relevance (salience) of the Eur-Agri-SSPs. With one-to-one nesting, we implicitly assume that all SSPs are plausible for the future of European agriculture and food systems, and that one Eur-Agri-SSP covers only one alternative global pathway. However, consecutive, one-to-one nesting has proven expedient for extending and enriching the SSPs because the SSPs are sufficiently disparate (Absar and Preston, 2015). Furthermore, the SSP rationale helps facilitators to manage strategic interventions or behaviors of stakeholders. The delineation of Eur-Agri-SSP4 (Agriculture on unequal paths) was most challenging because the focus of the global SSP4 on inequality required to first define whether and how European agriculture and food systems were divided, and then to establish the differences from the other storylines. Diversity of European agriculture and food systems and its consideration in the storylines was extensively discussed. For instance, a stakeholder suggested differentiating between Western, Southern and Eastern Europe, and some modelers stressed that regional heterogeneity can only partly be addressed in current model setups. Finally, the core and supporting groups decided not to provide details on diversity of the agriculture and food systems within Europe in order to leave room for Eur-Agri-SSP extensions and interpretation at national, sub-national and sub-sectoral scales.

Time mismatches between the SSPs and the Eur-Agri-SSPs are an additional potential challenge in a consecutive, one-to-one nesting approach (Kok et al., 2007). While the SSPs describe futures for the 21st century, the Eur-Agri-SSPs deal with the next three decades, i.e., until 2050. The shorter period was chosen because of stakeholders’ preferences for a time horizon consistent with their own actions and related effects and because it corresponds to previous storyline and scenario studies (e.g., Gramberger et al., 2011; Mylona et al., 2016; Vervoort et al., 2016). However, when using the SSP narratives, this problem does not materialise to its full extent. The SSPs were presented as ‘pathways in the 21st century’ (which can be interpreted as proto-scenarios, see Table 4) and O’Neill et al. (2017) do not refer to a specific end point. Not until the SSPs are elaborated to full scenarios, do they have a specific time horizon. Thus, the intentionally wide coverage of the SSPs and their trends are applicable throughout the 21st century which allows for regional and sectoral extensions with a shorter time horizon (Rohat et al., 2018), as successfully demonstrated by, e.g., Palazzo et al. (2017). We do acknowledge that the Eur-Agri-SSPs may have introduced developments that might be inconsistent with scenarios based on the SSPs developed for 2100.

4.6. Science-driven storyline development

For improved process transparency and because of the particular interest in applying the Eur-Agri-SSPs to research, we have chosen to follow a science-driven approach adhering to a protocol. Accordingly, we chose ‘scientists from the climate change, agricultural, food and integrated assessment research communities’ as a main target group (Section 3.1). ‘Policy makers in European agriculture and food systems’ and ‘decision makers in the private sector’ were added as main target groups because they may use the Eur-Agri-SSPs for designing policy or business strategies. Therefore, stakeholder activities provided essential inputs for the storyline development process. However, defining three main target groups brings about challenges because of their partly different interests and needs, such as on the required level of detail of the storylines. The scientists expressed two concerns, on (i) the level of integration of storylines and quantitative model-based integrated assessments of agriculture and food systems, and on (ii) the translation of directions of change for quantitative model-based integrated assessments of agriculture and food systems. Concern (i) refers to the extent to which the quantitative models can account for the storyline elements, and concern (ii) is about putting numbers on the directions of change, which can then serve as inputs for quantitative models. For both concerns, the suggested level of detail in the Eur-Agri-SSPs is closely related to their application in integrated assessments of agriculture and food systems. Thus, the storylines should provide sufficient detail for model parametrization and, at the same time, leave room for the modelers to implement in their specific study. In any case, it is advisable to document any remaining divergences. Policy and decision makers emphasized their interests in which interventions particular developments will be stimulated or slowed down and therefore preferred a comprehensive description of storyline elements related to policies and the economy. This preference combined with modelers’ needs for policy and economy specifications, resulted in an emphasis on policies and, in particular, on the economy. Similarly, O’Brien (2004) demonstrates that economic factors are often predominant in storylines and scenarios. Science-driven, interdisciplinary cooperation and participatory engagement throughout our research process helped to diversify storyline elements, to agree on the final storylines, and also to balance the diverging demands.

5. Conclusions and outlook

The Eur-Agri-SSPs describe plausible but contrasting futures of the European agriculture and food systems, characterized by a number of socio-economic, environmental and technological drivers and their interactions, which have been identified as particularly important and uncertain for the European agriculture and food systems. These drivers are based on the SSPs and Eur-SSPs but were strongly refined in a participatory process to satisfy researchers’ and stakeholders’ demands.

Both scenario methodological rigor and thematic depth facilitate a broad range of potential applications, including integrated assessments of agriculture and food systems, and policy and decision making. For their application in models, the Eur-Agri-SSPs need to be translated into a set of quantitative assumptions that are required to run numerical models. Further extensions of the Eur-Agri-SSPs would be useful to address national and sub-sectoral futures. We suggest to follow the nine working steps in the protocol in order to maintain the high level of transparency and reproducibility and to adjust the methods and the level of stakeholder engagement to the respective needs. If resources are limited, we recommend to focus on defining storyline elements and consistency checks. From our experience, they are critical for the credibility and wide acceptance of the final storylines. However, protocol-based storyline development does not prevent researchers from taking reasoned decisions where stakeholders disagree or raise arguments that are contradictory to the underlying SSPs. The authors would appreciate reports on any application of the Eur-Agri-SSPs as well as comments on perceived contradictions to enrich the database at https://eur-agri-ssps.boku.ac.at for methodological learning and resource sharing.

CRediT authorship contribution statement

Hermine Mitter: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Validation, Visualization, Writing - original draft. **Anja-K. Techen:** Conceptualization, Investigation, Methodology, Validation. **Franz Sinabell:** Conceptualization, Funding acquisition, Investigation, Methodology, Validation. **Katharina Helming:** Conceptualization, Funding acquisition, Methodology, Project administration, Supervision, Validation. **Erwin Schmid:** Conceptualization, Methodology, Validation. **Benjamin L. Bodirsky:** Validation. **Ian Holman:** Validation. **Kasper Kok:** Supervision, Validation. **Heikki Lehtonen:** Validation. **Adrian Leip:** Validation. **Chantal Le Mouël:** Investigation, Validation. **Erik Mathijs:** Methodology, Validation. **Bano Mehdi:** Investigation, Validation. **Klaus Mittenzwei:** Investigation, Validation. **Olivier Mora:** Investigation, Validation. **Knut Øistad:** Investigation, Validation. **Lillian Øygarden:** Validation. **Jörg A. Priess:** Supervision, Validation. **Pytrik Reidsma:** Investigation, Validation. **Rüdiger Schaldach:** Investigation, Validation. **Martin Schönhart:** Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Supervision, Validation.

Declaration of Competing Interest

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

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Appendix A. Supplementary data

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