UNISECO

UNDERSTANDING & IMPROVING THE
SUSTAINABILITY OF AGRO-ECOLOGICAL
FARMING SYSTEMS IN THE EU

Deliverable Report D4.2 Report on Participatory Scenario Development of Agro-ecological Farming Systems. Version 2.0.

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EXECUTIVE SUMMARY

The UNISECO project aims to provide recommendations on how the sustainability of agro-ecological farming systems (AEFS) in Europe can be promoted. These recommendations build also upon scenario development and assessment of territorial effects of a large-scale implementation of agro-ecological farming innovations in the EU. This Deliverable describes in detail the scenarios and related storylines developed with stakeholders and first results from the biophysical modelling of the five scenarios using the BioBaM model, and the economic modelling.

Five storylines were developed in a participatory process involving all project partners and project stakeholders. The main determinants of the storylines are their level of implementation of agro-ecological farming practises and the localisation of food system (i.e. level of trade within the EU and globally). The first storyline **Business-as-usual**, extends the dynamics and critical aspects of current agri-food systems into the future and highlights current policy barriers to the expansion of agro-ecology. The second storyline, **Agro-ecology-for-export**, depicts a future in which medium-large agricultural farms and large companies in the food processing and distribution sectors promote a weak agro-ecological approach as a marketing strategy. The third and fourth storylines describe a future in which food systems are localised but for different reasons. In both these storylines, local foods, regardless of production methods, are given priority over agro-ecological farming practises. In consequence, production practises remain similar to current ones or further intensify. **Localisation-for-protectionism** do this for reasons of rising nationalism and protectionism, and calls the centrality of the EU into question and promotes further re-nationalization of agricultural policies. The **Localisation-for-sustainability** on the other hand promotes local food system not for protectionist reasons, but in an ambition to increase food system sustainability and resilience by cutting food miles and diversifying local production systems. The fourth storyline, **Local-agro-ecological-food-systems,** reflects the implementation of more advanced stages of agro-ecological transition – redesign.

The qualitative descriptions of the storylines are translated into quantitative inputs to be used in the biophysical modelling, including quantifications of diets (determining total demand), waste, production levels, livestock diets etc. Storylines are modelled at the NUT2 level and results are presented for land use, biomass production and consumption, rates of self-sufficiency and greenhouse gas emissions. Results show that a decrease in land use, land use intensity and greenhouse gas emissions can be achieved without compromising food security and regional food self-sufficiencies. Drivers behind sustainability improvements are an overall reduction of the size of the food system measured in total land use and in particular in total biomass production and in particular biomass production. This is achieved by combining consumption-side measures that mainly aim at realising less animal source food in diets, and production side measures, that aim at shifting from crop-based to roughage-based animal production on the one hand (an agro-ecological systems re-design), and at distributing the different production activities to the regions where they can be done most efficiently, as well as efficiency increases in general (expected yield increases, etc.). The choice of the production systems itself – agro-ecological, organic, or conventional in this case – is less relevant for greenhouse gas improvements than the reduction of the quantities produced. If demand and supply side measures are applied together and in close coordination, trade-offs between less intensive agricultural production and putting land aside for nature-based climate solutions are possible. Thus, a more sustainable and less intensive form of agricultural production that implements agro-ecological practices does not necessarily come at a high price for climate-change mitigation if the size of the total food system is reduced.

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The results will be analysed further and more results will be added and analysed in the following months and reported in Deliverable D4.3 and publications in peer-reviewed journal articles. This will also include the assessments of the second biophysical mass-flow model SOLm, an intermediate assessment in 2030 and including an analysis of further indicators for environmental and social aspects, as well as certain economic assessments. The economic model finds that a combination of EU production taxes, EU consumption taxes, and EU import tariffs are sufficient to generate the quantity outcomes from the biophysical model. This deliverable contains some minor inconsistencies related to the qualitative storyline descriptions and the modelling input. The scenarios will be further refined in coming work to resolve these.

1. INTRODUCTION

This document describes the scenario development process that has been carried out to date within Task 4.3 in the UNISECO project. The overarching confronting question in UNISECO scenario development corresponds to one of the objectives of WP4 - what are the territorial effects of a large-scale implementation of agro-ecological farming innovations in the EU? Since the scenario development process is iterative (see section 3) descriptions of storylines and case study integration is subject to change as knowledge about the system under study increases as results from the modelling are gained.

The report is structured as follows: First, a short description of the use of scenarios and scenario development is given (section 2.1). A few existing studies based on the type of biophysical models that will be used in UNISECO are described shortly to give an understanding of the type of modelling that will be performed and outcomes of other previous modelling studies are briefly summarised (section 2.2). In section 3, the methodology and models used in UNISECO are described, including an overview of the stakeholder interactions to date and the main outcomes of these. Section 4 contains the results to date, including the five storylines in section 4.1 and the results from the biophysical modelling in section 4.2 and the economic modelling in section 4.3. Section 5 presents the overall conclusions so far from the EU level modelling in the UNISECO project. Results when agroecological innovations are implemented, will be included in Deliverable 4.3. This deliverable contains some minor inconsistencies related to the qualitative storyline descriptions and the modelling input. The scenarios will be further refined in coming work to resolve these.

2. BACKGROUND

2.1. The use of scenarios

Scenario development and other foresight activities have the common goal of enabling a structured way of thinking about the future and enable effective decision making (Wiebe et al., 2018). Scenarios are descriptions of plausible and possible futures that help investigate outcomes of different actions implemented today or in the future. A scenario has been defined as "*plausible and often simplified description of how the future may develop, based on a coherent and internally consistent set of assumptions about driving forces and key relationships*" (MEA, 2005). Scenarios are also useful for engaging with stakeholders to increase knowledge and awareness of a certain issue and of outcomes of certain actions. They are also used for highlighting and discussing trade-offs and synergies, and handle conflicts of interest.

There are many different types of scenarios. A useful typology is that presented by Börjeson et al. (2006) which divides the scenario types into *predictive*, *exploratory* and *normative* corresponding to the following questions "What will happen?", "What can happen?" and "How can a specific target be reached?" respectively. Predictive scenarios try to predict what a likely future will look like, using for example historic data, and are most useful for short-term planning purposes. A common assumption for predictive scenarios is that the existing governing systems stay constant within the period studied. When it comes to the agricultural sector, this could for example be agricultural policies and prices. A risk with predictive scenarios is that they can contribute to preserving past trends which might hinder desired goals. For example, predictive scenarios are often used for infrastructure planning based on historic data which might lead to increased investment in road

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infrastructure which often increase traffic and associated negative impacts instead of paving the way for alternative mobility systems.

In order to study how the future could develop, one can use exploratory or normative scenarios instead of predictive scenarios. Explorative scenarios are similar to predictive scenarios, but are to a lesser extent based on how the situation is today and instead provide alternative situations where major changes are possible. Normative scenarios are based on reaching a specific target (e.g. GHG reduction targets) in one or more areas. In order to realise exploratory or normative scenarios, larger trend breaks are often needed.

Scenarios can be developed in a multitude of ways. However, all scenario development processes follow the approach illustrated in Figure 1. The Confronting questions, i.e. questions about the future, provide the entry point. An example of such a question investigated by Bock et al. (2002) was “How can genetically modified, conventional and organic crops coexist in European agriculture?”. In the “Structuring dialog” step, stakeholders are engaged in order to create a sense of ownership of the scenario in order to maximise the impact of the scenario development process. Scenarios are then designed jointly by stakeholders and experts in the “Designing scenarios” phase. The degree to which stakeholders are involved varies depending on the purpose of the exercise. Stakeholders may give input to export-created scenarios, experts and stakeholders may co-design scenarios or stakeholders may lead the full process. Different approaches for the “Analysing impacts” phase are available, including qualitative and quantitative approaches. The latter involve modelling the outcomes of key variables. One of the most well-known scenario processes which is used extensively as a basis for quantitative modelling is the development of the Shared Socioeconomic Pathways (the SSPs) which are established by the climate change research community in order to study future climate impacts, mitigation and adaptation strategies (Riahi et al., 2017).

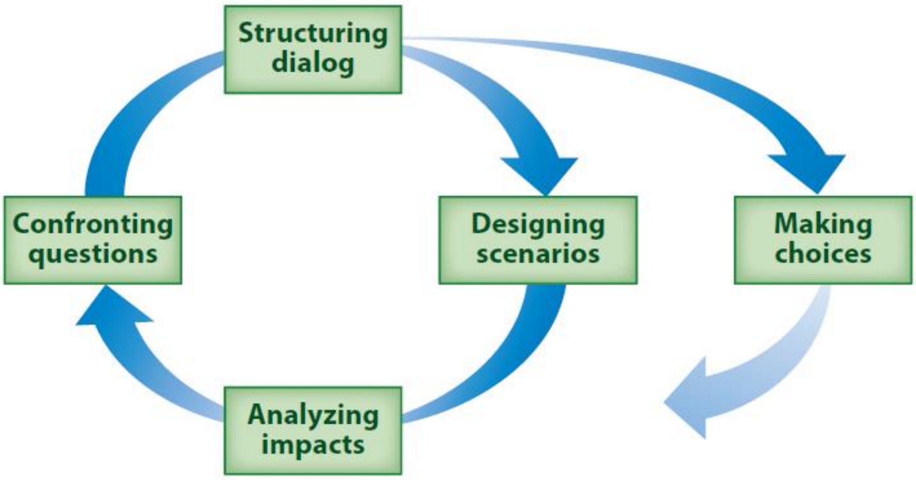

Figure 1: Key steps in scenario development and evaluation. From Wiebe et al. (2018).

Scenarios can be either purely qualitative or quantitative or include both qualitative and quantitative elements. A qualitative scenario is often called a scenario storyline or narrative and aims at creating an image of the future hence providing a broader perspective than quantitative modelling alone can do. Storylines describe the drivers of change, especially those for which the causal relationships within a system are not fully understood which prevents quantification of these in models. Storylines are especially useful for scenario

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studies covering longer timeframes as uncertainties are larger (Rounsevell et al., 2010). Using quantitative models to calculate the consequences of alternative futures provides a way to artificially perform experiments about behaviour of the system.

Wiebe et al. (2018) summarise some key learnings from years of scenario development and especially highlight the need for "*clearly formulated questions, structured dialog, carefully-designed scenarios, sophisticated biophysical and socioeconomic analysis, and iteration*" for more effective decision making for a highly complex and uncertain future. It is important to note that scenarios are not always predictions nor always desired or realistic futures, but functions to provoke our perception and thinking of the world. That said to be useful scenarios need to be internally coherent, and interesting and relevant to the target audience.

2.2. Recent scenario work related to food and agriculture

Several scenarios have been developed that focus on the agricultural and land use (see e.g. Audsley et al. (2006), Stürck et al. (2018) and Wolf et al. (2015)). Recently, scenario development has also expanded beyond agriculture to take a food systems approach i.e. including both production and consumption in order to be able to determine how different aspects 'add up' on the regional scale, e.g. the whole of the EU. The importance of including the consumption level has become increasingly clear during the latest years in which several such studies using this approach have been published. For example, as organic production requires more land than conventional production, the impression could be that it would not be possible to feed the world on the existing cropland using organic production. However, this conclusion rests on the assumption that food consumption patterns stay constant, i.e. the same amount of food will still be needed (Smith et al., 2019). If consumption changes (which is the case when prices or preferences change), a number of options for high shares of organic production emerge, also without increasing land use or encroaching into forests (Erb et al., 2016; Muller et al., 2017). Conversely, if European organic agriculture expands and consumption does not change that would mean that agricultural production would be pushed into other regions, possibly creating negative effects there. Therefore, in UNISECO we aim at taking a broad food system approach. Below, three recent studies taking a food systems approach, i.e. including both production and consumption, performed by UNISECO team members are shortly described.

A recent study from the Nordic countries used an extensive stakeholder process to develop scenarios of a future food system, including both production and consumption (Johan O Karlsson et al., 2018; Johan O. Karlsson et al., 2019). Researchers worked together with five NGOs over a period of a year to iteratively develop a vision for the future of food production in the Nordic countries (Sweden, Norway, Finland and Denmark). The final vision was based on organic farming and lower meat consumption with livestock fed on pasture and by-products from food production. Stakeholders designed the future food vision by pinning down for them important principles which were translated into consequences for the food system and hence the assumptions relevant for subsequent modelling. The researchers modelled the outcomes of such a scenario for the Nordic food system (in terms of land and energy use, greenhouse gas emissions, foods produced, N and P flows). The results were then shown to and discussed with stakeholders in several workshops and the scenarios were refined based on these discussions. Results were then disseminated mainly by stakeholders and used for communication and advocacy purposes e.g. at two COP-meetings and at several national seminars.

Muller et al. (2017) investigated how high shares of organic production perform regarding a number of environmental indicators covering land use, deforestation, GHG emissions, N and P surplus, soil erosion,

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pesticide use, cumulative energy demand and water use. They found that a switch to 100% organic production would result in large land use increases, by 30% in comparison to a business-as-usual scenario from FAO for 2050 (while not increasing GHG emissions). If combined with additional strategies, such as a reduction in food-competing feed (i.e. feed from arable land: cereals, forage maize, etc. that could be consumed directly) with correspondingly reduced shares of animal products in diets, and with reduced waste levels, food systems with 100% organic production are possible, and feasible across all the indicators investigated. A particular challenge for high shares of organic production is nutrient supply, as mineral nitrogen fertilizers cannot be used anymore.

Erb et al. (2016) developed a diagnostic model to assess the biophysical feasibility of 500 different scenario combinations of the global food system in 2050 without encroaching forests. Thus, they systematically combined realistic assumptions on future yields, agricultural areas, livestock feed and human diets. For each scenario, they determined whether the supply of crop products meets the demand and whether the grazing intensity stays within plausible limits, which they indicated as a feasible scenario. They found that many options exist to meet the global food supply in 2050 without deforestation, even at low crop-yield levels. Results showed, that within the option space, individual scenarios differ greatly in terms of biomass harvest, cropland demand and grazing intensity, depending primarily on the quantitative and qualitative aspects of human diets, and that grazing constraints strongly limit the option space. A recent study based on the same model (BioBaM) expanded the scope to also account for AFOLU emissions (Theurl et al., 2020). However, these studies only consider biophysical factors, economic costs and social desirability were beyond the scope of these study.

Apart from the above-mentioned studies there has been an increasing number of similar scenario development studies which all explore and attempt to predict what future developments could look like. One of the most comprehensive reports on the topic is the FAO's *The future of food and agriculture. Alternative pathways to 2050* (2019) which has served as the overall reference point in the scenario development in the UNISECO project (see section 3). Previous relevant scenario studies were reviewed in the UNISECO project in order to ensure uniqueness and relevance of the UNISECO scenario work.

It becomes apparent from previous work that drastic measures are needed to reach different sustainability targets. A good example of this is the Income & Environment-scenario in the Scenar 2030-report (M'barek et al., 2017) which shows that despite a restrictive compliance with agri-environmental objectives in the CAP and support levels being kept at current levels, key challenges in terms of environment and farmer incomes remain. It is also clear that for the environmental impact to be reduced in EU agriculture, production of especially animal products has to decrease which might negatively affect rural jobs. One way of achieving this is through further trade liberalisation and reduction in CAP support (the other scenarios in the Scenar 2030-report) – however such a strategy would not lead to overall decreases in greenhouse gas emissions (and other environmental impacts) as these would leak to other countries if consumption is not in some way moderated. This shows the need to handle both the consumption and production jointly, which is highlighted by several initiatives calling for an integrated EU food policy (e.g. iPES (2015)) or to accept trade-offs, as expressed in the Scenar-2030-report: "*As designing an agricultural policy that meets multiple goals is highly challenging, the policy might need to focus on some key objectives and accept the trade-offs*."

There is a clear line of division between scenarios aimed at minimizing the climate impact, like the NetZero-scenarios (Lóránt et al., 2019) and A Clean Planet for all-scenarios (EC, 2018), and scenarios that take as their starting point in an agro-ecological future, like the IDDRI-scenario (IDDRI, 2019), the FAO TSS scenario (FAO, 2018b) and also Johan O Karlsson et al. (2018), with the later approach aiming at taking into account aspects like conservation of natural resources and biodiversity, and adaptation to climate change (IDDRI, 2019). The main differences are summarised in Table 1. Note however that even strategies aiming to reach climate neutrality in agriculture fail to do so. From the NetZero-report: *"Yet, even with such extreme changes, emission reductions do not reach net-zero and therefore reaching a climate-neutral agriculture may require the sector to compensate some unavoidable emissions through existing carbon sinks in other land using sectors such as forestry."*

Table 1. Differences between scenarios aimed at reduced climate impact and with agroecology as their starting point

Climate focus	Agroecology focus
Large reduction of ruminant meat production and consumption	Large reduction in monogastric animals (as minimized feed-food competition is aimed for)
Intensive land use (increased yields and intensification of pastures) and animal production systems (breeding etc.) to spare land for carbon sequestration	More extensive land use (yields decrease in LIC)– a land-sharing approach or spared land is used for nature conservation
Both food and energy production from agricultural land is considered	Bioenergy production largely phased out and limited to e.g. biogas production on some biomass waste streams
Technology oriented	Nature based solutions prioritised

Some general conclusions from the existing scenario work are the following:

- The need to manage demand of animal products is highlighted in all reports but to a varying degree, if less emphasis is put on dietary change, the need for higher production levels increases
- How trade is managed is an important determinant for how food systems are organised
- There is different views on the need to produce non-foods on agricultural land, ranging from "managing the bioeconomy" to a total phase out of biofuel production
- If food is to be produced more sustainability, food prices will go up (especially if externalities are to be included in food prices), highlighting the need for a more equitable food system and society at large
- Significant investment and regulation (of e.g. trade) is needed to reduce negative impacts from agriculture

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3. METHODS

3.1. Overview of methodology and models

In UNISECO, explorative scenarios for EU food systems with a focus on the incorporation of agroecological practices will be developed. Outcomes will be compared to 1) a baseline of a business-as-usual future based on the current situation, and 2) existing EU or global targets (e.g. EU greenhouse gas reduction targets and available agricultural land in the EU). A set of different assumption in terms of food waste reductions (e.g. assuming current levels or waste reductions of 50%) and dietary patterns (e.g. current, projected, healthy diet) will be included to illustrate how such changes affect outcomes in combinations with implementation of case study innovations.

The overarching confronting question in UNISECO scenario development corresponds to one of the objectives of WP4 i.e. **what are the territorial effects of a large-scale implementation of agro-ecological farming innovations in the EU?**

Scenario development in UNISECO follow a ‘story and simulation’ approach (Figure 2). This means that stories (here after called storylines) that qualitatively describe possible future developments (Rounsevell et al., 2010) are first articulated. To have more information regarding a range of quantitative parameters, for example greenhouse gas emissions, land, water and energy use etc. these storylines are then translated into numerical input and modelled in order to describe these futures in numbers. Results are then again presented to stakeholders and their input is used to refine the scenarios.

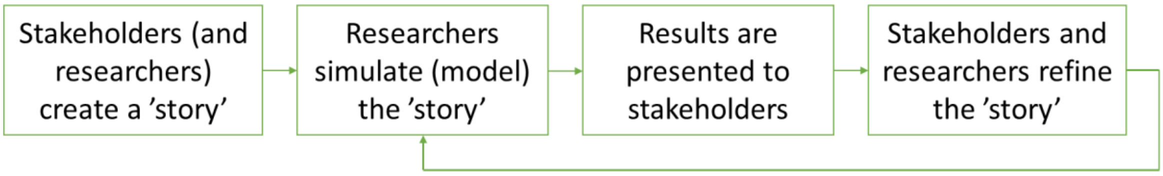

Figure 2: Scenario development approach in UNISECO.

The UNISECO scenario work builds on three main parts:

- The development of qualitative storylines providing a description of possible future developments
- Biophysical modelling providing information of consequences of biophysical outcomes from a combination of drivers (the option space) and outcomes from the specific storylines
- Macroeconomic modelling providing information on food prices, farmer income and policy options to reach the futures described in the storylines

Outcomes of these three parts form the UNISECO scenarios. Data and other input from a range of sources including the FAO scenarios (FAO, 2018b), the Decision Support Tools (DST) from WP3 and Eurostat, FAOSTAT etc. (see section 3.4, 3.5. and Deliverable D4.1). The modelling framework is depicted in Figure 3. This report presents the storylines and a subset of results from the biophysical models and the complementary economic analysis.

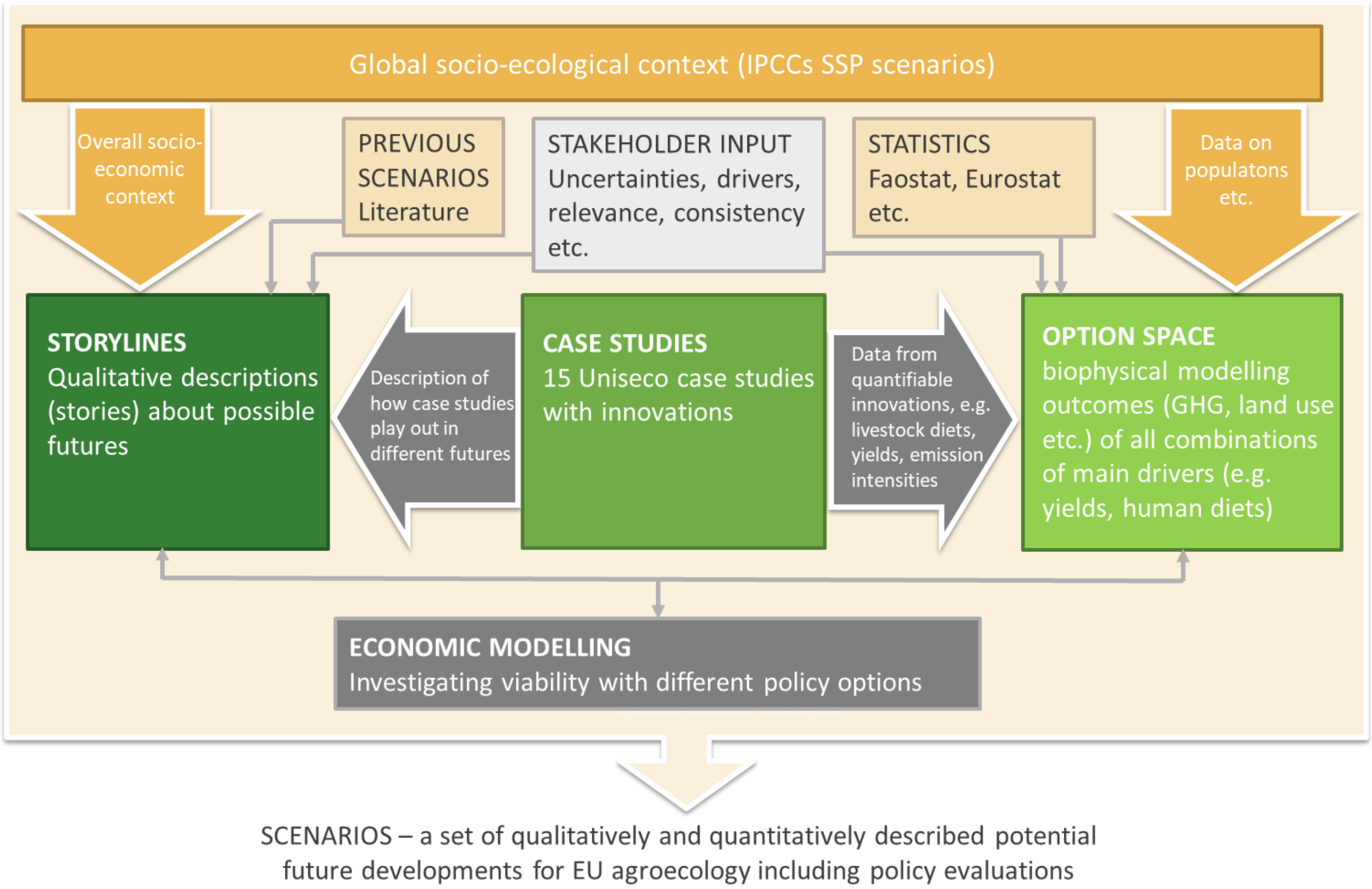

Figure 3: Scenario development framework in UNISECO.

3.2. Development of storylines

The commonly used and well-established matrix approach was used to create the storylines (Rounsevell et al., 2010). In this approach two important drivers or major uncertainties concerning the system under study are chosen and drawn out along two axis, forming a scenario cross. The axes create four quadrants, in which storylines consistent with the characteristics of the axes can be developed.

There are many challenges in successful storyline development. Storylines need to be salient (i.e. relevant to the policy question and stakeholders, explore a range of plausible futures including what could be considered surprises), credible (i.e. scientifically sound and consistent, revealing developers and stakeholder biases and expectations) and legitimate (i.e. societally accepted and transparent) (Pérez-Soba et al., 2015; Rounsevell et al., 2010). To ensure that storylines in the UNISECO project were salient, they were developed in an iterative manner involving EU level and local stakeholders. Stakeholder input was used to first identify the uncertainties on the two axes and then to iteratively refine the storylines. All project partners, hence representing knowledge and views from 13 EU member states and Switzerland and the UK, were also involved in the storyline development. Stakeholder interactions and their output is described in section 3.3. Stakeholder engagement was also used to ensure credibility and legitimacy of the storylines, and credibility is also given through (planned) publication of the scenario work in peer-reviewed journals.

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3.3. Stakeholder interactions and storyline refinement

Table 2 summarises the stakeholder interactions that have been taking place so far in the scenario development process in UNISECO. Under the table the main outcomes of the stakeholder interactions are summarised.

Table 2. Overview of the stakeholder interactions in the scenario development process in WP4.

Time	Activity	Participants
1rst of March 2019	First stakeholder workshop in Brussels with the following objectives: • Develop a shared understanding of the scenario development purpose and process • Create an understanding of which analyses are possible with the models that will be used in UNISECO and their relevance for EU policy assessment and development • Collect input from stakeholders on what should be explored in the scenarios	13 stakeholders representing the European Commission, farmer organisations and environmental NGOs, and 5 UNISECO researchers
9th of May 2019	Second follow–up workshop with stakeholders in Helsinki with the objective to further discuss the identified critical uncertainties; the level and type of implementation of agro-ecology and the level of trade.	14 stakeholders (PAG members and EU level MAPs), and UNISECO project members
July-Aug 2019	Written feedback from all project partners on the storylines, answering the following questions: • In what way (if any) do you find this scenario interesting and relevant? • Do you find this scenario plausible i.e. could the future develop in this direction? Are there current evidence of developments in this direction in your country? • As the scenario is described now do you see any major inconsistencies? • What kind of policy developments would be likely in this scenario? • How would your case study play out in this scenario?	All UNISECO project partners
14th of Nov 2019	Third workshop with stakeholders in Basel to gather feedback on the drafted storylines and further discuss issues of trade, case study innovations and policy.	19 stakeholders (PAG members, EU level MAPs and local MAP members), and UNISECO project members
14th of May 2020	Fourth workshop with stakeholders – online to discuss updated storylines. Participants focussed on one storyline each and guiding questions for the group discussions were the following: • What would agro-ecological farming practices look like in this future in your country/context in this future? Area-wise, product-wise, production system-wise. • How would conventional agricultural practices have changed in your country/context in this future? • How would human diets look like? What foods would be traded and where to/from? • What policies or other developments could lead to this future? Are there signs today in your country of developments in this direction?	25 stakeholders (PAG members, EU level MAPs and local MAP members), and UNISECO project members

	- If you find the scenario assigned to you not interesting / not plausible / not desirable – why is this?	
July-Aug 2020	Written feedback from all project partners on the refined storylines, answering the same questions as in the previous consultation.	All UNISECO project partners

At the first workshop in March 2019, the first discussion centred on the usefulness of the scenario approach in general, its pros and cons, and potential limitations to overcome. The purpose of this discussion was to gain insights that would make the scenario development in UNISECO relevant to stakeholders. Issues raised here included the necessity to include many environmental aspects, not just greenhouse gas emissions as has many previous studies, but aspects such as eutrophication and pollution of oceans, impact on biodiversity, as well as social and economic aspects. One limitation to date in modelling that was highlighted was the lack of spatial resolution. Another challenge to overcome is to include also social and economic sustainability aspects, most current food systems studies focus on environmental sustainability. However, stakeholders acknowledge the difficulty in modelling outcomes of policy implementation over long time periods. Stakeholders brought up the difficulty in building realistic and interesting dietary scenarios and the need for dietary scenarios to be country specific. Next, time horizons were discussed and there was quite strong consensus among stakeholders that a time horizon of 2030 would be the most relevant although 2050 was also deemed interesting in order to cover more long term developments. However, stakeholders justified using 2030 by alignment with the Sustainable Development Goals and the 2030 Agenda. There were quite strong opinions that 2030 is much more relevant and that UNISECO should definitely include 2030, at least as a linear development until 2050 and including 2030 as a mid-point.

In order to find the critical uncertainties on which to base the scenario development, stakeholders were further asked to give their view on the most important uncertainties related to the future supply and food in the context of the UNISECO project. Food security/food sovereignty in relation to open-trade was a key issue raised by several stakeholders. There were differing views on what is preferable here and to what degree food should be traded internationally. This is relevant on an EU scale i.e. self-sufficiency of the EU versus global trade, but also within the EU. For example, investigating the benefits of keeping supply chains short. However, stakeholders highlighted that scenarios have to be plausible to be relevant (for example, closed border scenarios are not relevant), while they can show a range of trade options. In addition, as agro-ecology supports food sovereignty and EU is for open borders, there are concerns with agro-ecology for that reason. Other uncertainties that were mentioned included climate change and loss of biodiversity (e.g. pollinator) impacts on yields, the level of bioenergy production, biotechnology, the level of segmentation of markets (local foods, expensive luxury foods etc.) and implementation of precision farming.

Based on the discussions at the first stakeholder workshop it was decided by the WP4 team to continue with the following two critical uncertainties as the main focal issues in the scenario development; 1) the level of implementation of agro-ecological farming practises, and 2) the localisation of food system (i.e. level of trade within the EU and globally). Therefore, in Helsinki a short follow-up workshop was held in which stakeholders were asked to give their view on these issues. Based on these discussions the WP4 team drafted four initial storylines (qualitative descriptions), see section 4.1 for an overview. These storylines were sent out to all project partners which were asked to reflect upon the relevance, plausibility and consistency of the storylines, and to consider how their case study would play out in the different scenarios. Based on this feedback, the storylines were refined and thereafter sent out to stakeholders participating in the Basel project meeting in November 2019. Here the storylines were discussed in a large group among participants. The major critique raised by several stakeholders and also some project members was the nationalistic framing of the future in

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which local food systems developed in combination with a low level of implementation of agro-ecology. However, other stakeholders and project members found that future highly relevant and interesting. To cater for this, a fifth storyline was added (see section 4.1 and 4.1.5). Based on these discussions, the WP4 team also further refined storylines and also aligned them more with the SSP scenarios. On an online workshop (due to the COVID-19 situation) the updated storylines where discussed with stakeholders and project members in four breakout groups. Each group discussed one of the storylines each (except the Business-as-usual storyline) focussing on finding inconsistencies in scenarios and anchoring then more in local contexts. The storylines were slightly updated based on discussions in the groups and sent out again to all project partners to gather further input. However, no major revisions were made at this stage as feedback as no major inconsistences were pointed out at this point. Outcomes from the online workshop were also used to refine modelling input, i.e. the translation from storylines to quantitative model input.

3.4. Biophysical modelling

3.4.1. Overview of BioBaM and the SOL model

In UNISECO, two biophysical mass- and nutrient-flow models – BioBaM and SOLm – are used to model the outcomes of the storylines. In these models, the EU is divided into 227 regions (NUTS2-level, for more details see Uniseco Deliverable 4.1). The aim of applying BioBaM and SOLm is to understand the wider scale implications and feasibility of the diffusion of agro-ecological farming systems at different spatial scales and across a range of consumption levels. BioBaM is spatially explicit and thus provides the basis for detailed spatial assessment and allows for integration of the impacts of land use change induced by the diffusion of agroecological farming systems. It covers (1) changes in the flows of biomass from cropland and grasslands and induced land use changes, (2) GHG emissions from agricultural production including upstream flows and land use change, and (3) biodiversity pressures as indicated by the HANPP (human appropriation of net primary production) framework. SOLm in turn follows a similar approach, it is however not spatially explicit, but relies on more detailed modelling of agronomic aspects of the production systems (e.g. for animal production systems with herd structures and correspondingly differentiated feed supply, nutrient excretion and emissions), thus providing the basis for detailed assessment of various production systems. For a detailed description of the two models, see Deliverable 4.1.

As mass- and nutrient-flow models, BioBaM and SOLm do not include an endogenous decision structure, such as an assumption of profit-maximizing farmers. They serve to line out the biophysical option space of potential agro-ecological futures with a focus on potential synergies and trade-offs between different aspects. This allows for assessment of the biophysical viability of various storylines developed in participatory workshops without any restriction on how farmers may make their decisions on farming operations, on how these production changes may affect prices and on how consumers and trade may react to price changes. Evaluation of the consequences of these scenarios in a political and economic context is thus not part of these two models but is assessed separately by complementary macroeconomic modelling. This then indicates how compatible certain scenarios in the option space are with common economic incentive and decision structures, how much these scenarios may deviate from the current or business as usual future situation, and how strong potential economic instruments or assumptions on changed consumer preferences thus may need to be to achieve those scenarios. This approach facilitates transparent analysis of the system-specific trade-offs and synergies and helps to identify the option space within which societally acceptable solutions then have to be found. This

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report is limited to the results obtained with the BioBaM model. Results from SOLm will be presented in Deliverable 4.3.

3.4.2. **Indicators used**

Key indicators to capture and communicate the results from models cover the central aspects of the sustainability of agro-ecological farming on EU-level. The core results will be presented on aggregate EU level with due regionalisation (down to NUTS 2), based on the results from the two models BioBam and SOLm.

The main strength of BioBaM and SOLm is the combination of a broad variety of different parameters supply and demand food system parameters such as cropland and grassland yields, area expansion, livestock systems, and human and livestock diets. The models assess the biophysical feasibility of these combinations, which are considered as different options in the option space, and are able to show systemic interlinkages between the individual parameters, e.g. synergies and trade-offs at higher spatial and thematic levels. These parameters are currently: Human diets, livestock diets, wastes and losses (demand side), and cropland yields, grasslands yields, maximum cropland allowances. Baseline data is taken from the CAPRI model (Britz et al., 2015) and complemented with additional data where necessary (Herrero et al., 2013; Plutzar et al., 2016). Currently, the ranges of these parameters for the scenarios in 2050 are derived from well-established and published agricultural outlooks such as the Food and Agriculture Organization (FAO or the EAT-Lancet commission). In BioBaM, a series of indicators and environmental effects are calculated for each storyline (see Tables 3a and 3b). For more details on indicators listed in Table 3a, see Deliverable D4.1.; details on the indicators listed in Table 3.b follow right after it.

Table 3a. Overview of the indicators used in BioBaM.

Indicator	**Items**
Land use (Mha)	Cultivated cropland
	Grazing land
	Fallow cropland
	Cropland converted to grazing land
	Cropland left to natural succession
	Grazing land converted to cropland
	Grazing land left to natural succession
Cropland area by cropgroups (Mha)	14 crop groups
Grazing land by classes (Mha)	All grazing class names and 'original cropland'
Net imports by cropgroups (Mt)	All cropgroup names
Crop production (Mt)	All cropgroup names
Crop consumption for food (Mt)	All cropgroup names
Crop consumption for feed (Mt)	All cropgroup names
Crop residues used as feed (Mt)	Crop residues
Crop consumption for feed by agriproduct (Mt)	All agricultural product names , followed by ' - ' and all cropgroup names
Crop residues used as feed by agriproduct (Mt)	All agricultural product names , followed by ' - crop residues'
Crop consumption for other uses (Mt)	All cropgroup names

Agri.products production (Mt)	All agricultural product names
Agri.products consumption for food (Mt)	All agricultural product names
Agri.products consumption for other uses (Mt)	All agricultural product names
Grass supply (Mt)	All classes
Grass demand (Mt)	Total grazed biomass
Grazing intensities (1)	All grazing class names and 'original cropland'
Potential self-sufficiency (1)	Land-based self-sufficiency on region level
	Land-based self-sufficiency for regional aggregates level 1
	Land-based self-sufficiency for regional aggregates level 2
Self-sufficiency (all crops) (1)	all crops
Self-sufficiency by crops (1)	All cropgroup names
	All cropgroup names
	All cropgroup names
Self-sufficiency by agri.products (1)	All agricultural product names
	All agricultural product names
	All agricultural product names
GHG emissions from land use change (annual) (Mt CO_2e)	Total annual LUC emissions
GHG emissions from land use change (cumulative) (Mt CO_2e)	Total cumulative LUC emissions
GHG emissions from manure management (Mt CO_2e)	All agricultural product names
GHG emissions from enteric fermentation (Mt CO_2e)	All agricultural product names
GHG emissions: upstream emissions by cropgroup (Mt CO_2e)	All cropgroup names
TBA: Harvested biomass as share of total NPPpot (1)	A proxy indicator for HANPP, the human appropriation of net primary production
Regional grazing feasibility (1)	Regional grazing feasibility

Table 3b. Overview of the additional indicators provided by SOLm.

Indicator	**Items**
Crop water use (m3)	Blue water footrpint
	Green water footprint
	Grey water footprint
	Irrigation water use – scarcity adjusted
	Irrigation water use (i.e. alternative data source for blue water footprint)
Labour use (h)	Total labour use
Production value (Euro)	Production value
Labour productivity (Euro/h)	Production value per unit labour input
Animal welfare (index)	Antibiotics use

	Production intensity
	Heat stress
	Transport of living animals

Agriculture requires huge amounts of irrigation water. This is captured in SOLm by two datasets: First, the data from (Pfister, Bayer et al. 2011) on average irrigation water use per crop and country, and scarcity adjusted irrigation water use per crop and country (this accounts for downstream lack of water due to irrigation uses; for details, see the original publication). The data is provided on a per ton production basis (m3/ton), and it is transformed to per hectare values by multiplication with crop yields (which may depend on scenario assumptions).

Second, the data from the Water Footprint Network (Mekonnen and Hoekstra 2010) is available, containing values for green, blue and grey water use, for details see the publication. Again, the data is provided on a per ton production basis (m3/ton), and it is transformed to per hectare values by multiplication with crop yields (which may depend on scenario assumptions).

Both these data sets do NOT account for changes in water availability, precipitation patterns etc. due to future climate change, but reflects the situation in the respective base years, that lay around/before 2010.

The data is available on country level, but the footprint data is also available on NUTS2 level and can be utilized on this level as well, if needed.

Labour use in agriculture is a relevant indicator to assess a number of topics from changes in job availability (job creation/losses) in different scenarios, to various indicators of labour productivity, e.g. related to value generation per unit labour input. The labour data currently used in SOLm is very generic (cf. below) and may less be used to compare absolute numbers than gross relative changes between scenarios and regions; the same caveat applies to the use of labour productivity numbers derived from the available labour and price data. First, we have data from the Swiss “Deckungsbeitragskatalog” DBK (Agridea und FiBL 2020). This is Switzerland-specific data, but it is then used in EU countries as well by scaling the total labour used derived for the baseline with this data by the total labour use as reported by Eurostat. This proportion factor is then applied in all scenarios to adapt the Swiss labour Use data to EU countries. For other countries, such scale factors yet need to be developed.

The Swiss data neither covers all relevant crops - thus, some additional data is needed. In particular the data from the DBK does not cover vegetables. Data for labour use in vegetable production is taken from a publication specifically referring to vegetable production in Switzerland, using data from 2008/2010 (Möhring, Mack et al. 2012), Figures 1 (conventional) and 4 (organic: argument to use double the conventional value for labour use in organic vegetable production). Labour use is differentiated for several categories of labour, but we use total labour use only in SOLm. Some yet missing data for crop operations is then assigned based on similar crops (see code for details).

For labour use in livestock operations, the CH DBK has detailed labour use data as well, but not on an optimal level of detail/aggregation to match the animal categories as used in SOLm. Thus, for a fast indication, we use the data from page 362 in (Beattie 2019). This provides very generic labour use data per head and year for the different livestock categories; for part of the livestock, it is a very gross choice of a generic average - e.g. for chickens.

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Animal welfare has many dimensions and is difficult to assess in a global model. We focus on four dimensions of animal welfare that are adequate for modelling in SOLm on the one hand, and also cover four different aspects of animal welfare. These aspects are 1) production intensity; 2) antibiotics use; 3) heat stress; and 4) transport of live animals.

Currently, the data for animal welfare is available for the EU only (besides the intensity index, which is derived for all regions where the needed data is available, which basically covers all countries globally).

1) The data for production intensity are derived from other data available in SOLm.
    a) For ruminants, this is the share of concentrate feed in the feeding rations, i.e. use the share of non-grass in feeding rations: the higher, the lower is animal welfare
    b) For monogastric meat, this is the ratio of producing over living animals (for meat production) - this is a gross indication of the duration to gain the end weight: the shorter, the more intensive, i.e. the bigger is the ratio (more producing per living)
    c) For eggs, it is the egg yield in tons per head.
2) Antibiotics use is captured via an index of antibiotic use on all animals from (Van Boeckel, Brower et al. 2015). It thus is used by multiplying it with animal numbers to get a gross total antibiotic use index - assuming that the same regional use prevails in the scenarios. The index is then also corrected for animal intensity, assuming that less intensive systems use less antibiotics. The resulting index then represents a mixture of reported institutional settings and intensity. Furthermore, antibiotics are used according to the following weights on different animal categories: 1/8 bovine, 3/8 chicken, 4/8 pigs (Van Boeckel, Brower et al. 2015). Thus, we adjust the index accordingly and take 1/8 of the index as a basis for all livestock, then multiply with 3 for poultry, with 4 for pigs.

   To arrive at total values, the index is then multiplied with production levels, as it stands for antibiotics inputs per kg meat (and not per head or such). We include antibiotics use in milk and egg production by adding this to the meat production the multiplication takes place on, thus accounting for those outputs as well on the level of the aggregated index.
3) Heat stress is captured via three values, one referring to a period around 2020, one to a period around 2030 and one to 2050. The original data contains the values for 2020 and 2030 only, the 2050 value is very indicative only and is derived by linear extrapolation of the change from 2020 to 2030 (i.e. adding this change twice to the value for 2030). The data for heat stress for health is used as computed by copernicus in crp45 scentio based on EU health definition on apparent heat on band 035, i.e 12418 days since 01.01.1986 for 2020. This results in a heat stress index per animal head and total values are derived by multiplication with animal numbers (no differentiation between animal types).
4) Transport of live animals is the least reliable index, as it heavily depends on trade structures, etc. and may considerably change in scenarios. Per default, the trade in live animals in relation to total live animals is assumed to be fixed in scenarios (if not otherwise specified) and this ratio is also the index used. The data for trade in live animals is taken from UN Comtrade and is available on country level only. The ratio of trade in living animals over total living animals is the index to then be multiplied with total animal numbers, thus resulting in an aggregate animal welfare impact index related to trade in living animals.

In this deliverable, the following headline indicators are calculated:

1. Total GHG fluxes resulting from a) the emissions from soil management through the application of fertilizers, manure application and amounts of crop residues that are left on fields, b) emission from manure management, c) the upstream emissions for the external inputs, i.e. mineral fertilizers, fossil

fuels required for land management (see below), d) emissions from enteric fermentation as well as e) carbon sinks created due to land abandonment (see above). This assessment follows IPCC best practice guidelines (Dong et al., 2019). Additionally, we draw a distinction between GHG emissions including or excluding carbon emissions from land use change.

2. A surrogate indicator for the "Human Appropriation of Net Primary Production", an index for land-use pressures on biodiversity, was constructed by calculating the total amount of agricultural appropriation (TBA) per prevailing potential NPP on each NUTS2's utilized agricultural area (see, e.g. Erb et al. (2016); Pelletier et al. (2010)).
3. For all NUTS2 regions the self-sufficiency ratio (domestic production per domestic consumption) for crop products and monogastric and ruminant livestock products is assessed (Mayer et al., 2020).
4. Irrigation water use
5. Various animal welfare indicators, to give a gross indication of how animal welfare challenges may change in the different scenarios and in different regions.
6. Labur use and labour productivity. This allows a gross assessment of changes in labour use in the various scenarios and how this may affect different regions. Similarly, labour productivity changes are investigated.

3.4.3. **Modelling input**

In order to model the outcomes of the qualitative storylines, these had to be translated into quantitative input for the biophysical models. The model input for the different storylines are summarised in Table 4. (This deliverable contains some minor inconsistencies related to the qualitative storyline descriptions and the modelling input. The scenarios will be further refined in coming work to resolve these.)

Table 4. Model input for the different storylines. RUMI = ruminant livestock, MONO = monogastric livestock. EFF = efficiency, CL = Cropland, GL = Grassland, EU = European Union, Row = rest of world, NUTS = Nomenclature des unités territoriales statistiques, BAU = business as usual, LS = livestock, AE = agro-ecology.

	BAU	**Agro-ecology-for-exports**	**Localization-for-protectionism**	**Localization-for-Sustainability**	**Local-agro-ecological-food-systems**
Population	FAO 2019. Country-wide changes applied to NUTS regions				
Diets	FAU BAU	FAO TSS	FAU BAU	EAT-*Lancet* (Willett et al. 2019)	EAT-*Lancet* with higher shares of beef/dairy instead (Willett et al. 2019)
Waste levels	Current levels	Current levels	Current levels	-50%	-50%
Livestock diets	CAPRI (EU), Herrero et al. (2014) for RoW	Grass-based RUMI, -10% EFF MONO	CAPRI (EU), Herrero et al. (2014) for RoW	CAPRI (EU), Herrero et al. (2014) for RoW	Grass-based RUMI, -10% EFF MONO

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Animal products distribution	Current patterns	AE re-distribution to CL/GL potentials within EU	AE re-distribution to CL/GL potentials within country	AE re-distribution to CL/GL potentials within country	AE re-distribution to CL/GL potentials within country
Cropland expansion (allowance)	+20%	+70%	+70%	none	none
Maximum Grazing intensity (Harvest/NPPact)	Standard	Standard	Intensification	Extensification	Strong extensification
Conventional yields	BAU	BAU	BAU	BAU	BAU
Share Conventional	Same as in 2012	All other	75	75	50
Share Organic / AE	Same as in 2012	Fruits, Vegetables, Nuts (100% Organic)	25	25	50
Cropland yields: organic/AE systems	Lower yields for all crops (based on Ponisio et al., from Seufert et al. 2018), reflecting also areas needed for legumes, no fossil-based N fertilizer				
Trade clusters	Global trade, no restrictions	EU-wide trade first, then to RoW	Country-wide trade first, global trade only if deficits Surplus production in Europe for exports.	Country-wide trade first, global trade only if deficits	Country-wide trade first, global trade only if deficits

Implementation of baseline practices

The baseline consists of the current mixture of conventional and organic systems, i.e. the cereal yields per NUTS2 region are the result of organic and conventional systems in BioBaM. We define the baseline as the 2012 mix.

Baseline practices are the same across scenarios. Cropland yields, livestock feeding efficiencies, nitrogen use and energy efficiencies in the agricultural sector develop according to projections in the FAO Business-as-usual scenario. As for other land uses, e.g. fibers and biofuels, these were accounted for according to the FAO commodity balances as in 2012 (FAO, 2018a) and held constant across all scenarios.

Diffusion rate of agro-ecological practices

For the scenarios with a low level of implementation of agro-ecological practises we model these as if the implementation rate does not change, i.e. it corresponds to the current situation (data from 2012) for the Business-as-usual scenario and a 25% implantation rate for the Local-for-protectionism and Local-for-sustainability scenarios. This baseline situation includes a combination of organic and conventional production reflecting the situation in 2012. The land under organic practices in 2012 was 5.7% in the EU, ranging from 0.3% on Malta to 19% in Austria (Eurostat, 2020).

In the scenarios with high implementation of agroecological practices (AE-for-exports and Local-AE-food-systems), we model this as a 50% diffusion rate in terms of land use under agroecological practises in 2050 for the Local-AE-food scenario. (The EU Farm-to-Fork strategy has a goal of 25% of organic farming in 2030). In the AE-for-exports, AE practices will only expand for certain export-oriented products. These are fruits,

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vegetables, and nuts. In the Local-AE-food-system we assume the same diffusion rate for all crops and livestock production systems i.e. 50% of all wheat, 50% of all pork (however total absolute numbers of these will change following dietary changes i.e. food demand).

Implementation of agro-ecological practices in models

The implementation of agroecological practices in cropping are modelled as yield reductions based on Ponisio et al. (2015) which in turn determines the needed nitrogen input (according to crop needs). If land use is under organic practices, an area of legumes is added in order to supply nitrogen.

As for livestock diets, the starting point in BioBaM are the livestock diets from CAPRI for the EU, while for the rest of the world livestock feeding ratios from Herrero et al. (2013) were taken. CAPRI livestock diets were converted to feed conversion ratios, i.e. feed input (DM) / animal product (DM). The differences between organic and conventional monogastric production, was implemented as a yield gap of 10%. For eggs, the yield gap refers to output per animal per year; for pork, the yield gap refers to slaughter weight. In organic systems, often the same slaughter weight as in conventional systems is reached, but after a longer time (and higher feed use) than in conventional systems. The model is set up in such a way that this can be captured equivalently by using a lower slaughter weight. In the agro-ecology for exports and the local AE-systems scenarios, ruminant livestock production is based on grass and by-products from sugar and oil crops (amounts depending on local availability) only.

Livestock production in all scenarios except Business-as-usual is re-linked to domestic production potentials. This means that in the Localization-for-protectionism, Localization-for-Sustainability, and Local-AE-food-systems ruminant and monogastric livestock production in the year 2050 follows grassland (ruminant livestock) and cropland (monogastric livestock) production.

Diets and waste

In the Business-as-usual, and the Local-for-protectionism scenarios, the diets follow FAO Business-as-usual projections, in the Agro-ecology-for-exports scenario follows FAO TSS projections (i.e. a sustainability oriented scenario), while in scenarios Local-for-sustainability and Local-AE-food-systems, diets change to reach the EAT-Lancet diet (Willett et al., 2019) in 2050. In Local-for-sustainability, amounts of foods follows the EAT-Lancet strictly while in the Local-AE-food systems, ruminants are linked back to land, i.e. increasing ruminant production in Europe to a maximum extent of domestic grassland biomass and by-product biomass availability per NUTS region. By-products will be complemented with cereals to accomplish suitable pig/chicken diets. If the red meat limit is reached, only chicken will be produced instead if there are remaining by-products (on by-products and some cereals).

Trade

The self-sufficiency rates of regions and countries in cropland products depend on the area availability and diets. Thus, if domestic cropland from the year 2012 is not enough to cover local demand, cropland expansion into suitable grasslands is allowed. For example, in the Localization-for-protectionism scenario, a 70% expansion of cropland into suitable grassland in relation to the land use in year 2012 is allowed. If this is not sufficient, regions are allowed to import. In the Agro-ecology-for-exports scenario, net-deficits in EU regions are firstly covered from surplus within the EU. If regions have spare cropland and global demand exists, regions utilize cropland for the production of export goods, high value products (fruits, vegetables, nuts) are produced in an agro-ecological system. We distinguish three trading cluster. Firstly, within one country, secondly within the European Union, thirdly global trade. We further prioritize imports from specific trade clusters in each scenario, and only if these are not sufficient to close net-trade deficits, trade from beyond the prioritized

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cluster is allowed. The implications of these trade clusters are that if deficits occur, domestic (i.e. NUTS-level) production is increased first (thus increasing local land use), and then additional production is covered from higher-ranking territories (country, EU, global).

Additional indicators from SOLm

BioBaM produces area use patterns based on the scenario inputs and the internal optimisation calculations. These land use patterns are the input to SOLm, which then calculates animal numbers and the related derived indicators (animal welfare), as well as the other additional indicators, that are derived on a per unit basis times the relevant units (areas in hectares; livestock numbers; livestock and crop production)

3.5. Economic modelling

3.5.1. Overview

The main purpose of the economic modelling in WP 4 is to investigate the economic impact of future storylines/scenarios and innovations studied in the biophysical models vis a vis the 2050 Business as Usual baseline. This economic modelling analysis allows us to infer how changes in quantities of agricultural products produced, consumed and traded leads to changes in prices of those commodities. The economic model also allows us to study which economic policies or combinations of policies can be used to obtain the outcomes of the biophysical models for each storyline/scenario. The combination of prices and quantities also allow us to measure the economic impacts in terms of economic well-being and employment.

3.5.2. Data

The economic analysis is restricted to tradable agricultural commodities, using the same classification of commodities as the biophysical models. The economic analysis is carried out separately for 12 commodity groups used in BioBaM and SOLm.

The analysis focuses on two aggregated regions: the European Union and the “Rest of the World”. The EU can be treated as a single region because it is a customs union and has harmonized its economic and trade policies in the agricultural sector via the Common Agricultural Policy (CAP).

The economic model requires input data on quantities produced, consumed, and exported in each of the two regions, which we take from the biophysical models. BioBaM provides the production/consumption data, and SOLm provides the detailed trade flow data. We require this quantity data for the baseline (2050 BAU), as well as for each scenario in 2050. The list of commodities included in the analysis as well as the quantities of production, consumption and trade for the EU and the Rest of the World are provided in Table 5. EU Production greatly exceeds imports for most commodities, with the exception of “other crops”, which is driven by the import and export of coffee.

The economic model requires data on prices of the commodities, which we take from the most recent year of FAOstat. The commodities in the biophysical models are grouped into major food categories, so we must choose a price for a particular good and country. The choice of price statistics affects the magnitude of the economic welfare and employment results, but not the results for the policies required or the predicted percent change in prices. The economic model also requires data on the elasticity of supply and demand for

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each commodity. These elasticities determine how prices respond to changes in quantities produced and consumed in the model, and the value of these parameters is crucial for the results.

In part of the analysis we use the own-price demand elasticities estimated by Seale et al. (2003) for high-income countries. Supply elasticities are less well researched in the literature and we use the upper and lower bounds of the supply elasticities used in the Global Trade Analysis Project (GTAP) model (McDougall, 2016; Hertel et al., 2016). The assumed prices, supply elasticities and demand elasticities from the literature are provided in Table 6. The 2012 price in Germany is used for all commodities except coffee, which uses the 2012 Brazilian price instead.

The larger the demand or supply elasticities are, the more sensitive are the quantities consumed or produced respectively to price changes. Over the very short-term, food consumption and production tends to be relatively insensitive ("inelastic", in the jargon) to changes in price, with elasticities close to zero. However, production and consumption are more responsive to prices in the longer term as consumer preferences or production technologies adapt, implying that "long-run" elasticities are larger than "short-run" elasticities.
As we are studying the impacts of different scenarios 30 years from now, one could argue that demand and supply may be less sensitive to price in such a long-run scenario as tastes and technology adapt to changing market conditions. Therefore, as a robustness check, we provide the results when we assume more elastic supply and demand elasticities. We analyze two different sets of elasticities, first assuming a supply elasticity equal to 5 for all goods, then assuming a demand elasticity equal to -1.

Another important point about elasticities is that small elasticities typically seen for agricultural commodities imply that a relatively large change in price-influencing policies is required in order to bring about a small change in the quantity demanded or supplied. For example, if the demand elasticity is -0.1, this would imply that a tax must increase the price by 100 percent in order to bring about a 10 percent decrease in the quantity demanded. In contrast, prices would only increase by 10 percent if the demand elasticity equals -1. This implies that even modest changes in quantities predicted by the biophysical models would require relatively large policy changes in order to square with the economic model if the elasticities are highly inelastic.

3.5.3. Modelling Approach

The analysis uses a partial equilibrium model of trade called an "equilibrium displacement model". This model was first developed by Muth (1964) and has been used in many studies of international trade, with prominent studies by Sumner and Wohlgenant (1985), Gardner (1987), and Alston et al. (1995).

As with any model, the equilibrium displacement model has several advantages and limitations. The attractive properties of equilibrium displacement models are that they need very few inputs, they are flexible, and they are also tractable enough to allow for finding analytical solutions. Their drawbacks include that they only model a single market ("partial equilibrium" in the jargon) and do not model the whole economy or complex interactions between markets. As with most models, they are not as trustworthy when studying large deviations from the baseline.

Table 5: List of commodities and associated production, consumption and trade, EU and Rest of the World, 2050 Business as Usual, million tonnes

Commodity	EU Production	EU Consumption	EU Exports	RoW Production	RoW Consumption	RoW Exports
Cereals	442.0	438.8	56.9	3874.8	3840.6	35.9
Fruits	109.0	136.5	10.7	1073.0	1051.3	36.9
Nuts	1.0	2.9	0.2	17.2	15.1	1.9
Oilcrops	300.3	613.3	27.7	3299.3	2972.8	320.4
Other crops	3.0	11.9	13.5	282.7	275.7	27.4
Pulses	3.1	3.9	0.6	111.6	109.6	1.5
Roots and Tubers	103.9	97.2	6.5	1014.9	1028.9	1.2
Sugarcrops	522.5	583.4	1.8	6265.5	6135.2	124.6
Vegetables	118.8	117.0	5.8	1362.2	1355.1	5.4
Milk	365.7	342.7	27.4	1593.0	1605.2	2.5
Meat	63.2	56.8	6.2	432.0	430.9	1.2
Eggs	8.4	8.2	0.3	106.8	106.6	0.1

Source: BioBaM and SOLm.

Table 6: List of commodities and associated prices and elasticities, 2012

Commodity	Product used for price data	Price per tonne, USD, 2012	Supply elasticity	Demand elasticity
Cereals	Wheat	319	0.24	-0.287
Fruits	Apples	558	0.24	-0.287
Nuts	Almonds, with shell	1153	0.24	-0.287
Oilcrops	Soybeans	567	0.24	-0.158
Other crops	coffee, green	3000	0.24	-0.287
Pulses	Beans, dry	2428	0.24	-0.287
Roots and Tubers	Potatoes	317	0.24	-0.287
Sugarcrops	Sugar beet	44	1.12	-0.287
Vegetables	Tomatoes	694	0.24	-0.227
Milk	Milk, whole fresh cow	391	1.12	-0.288
Meat	Meat, pig	1733	1.12	-0.288
Eggs	Eggs, hen, in shell	2436	1.12	-0.288

Notes: The price data is for Germany for all goods except coffee, which is taken from Brazil. The price data is taken from the FAOstat database. Demand elasticities are taken from Seale et al. (2003) for high-income countries. Supply elasticities are taken from the Global Trade Analysis Project (GTAP) model (McDougall, 2016; Hertel et al., 2016).

The economic model is a set of equations that defines the interaction between changes in prices, quantities and policy variables in a market. In our case, the market is a particular BioBaM/SOLm food commodity produced, consumed, and traded between the EU and the Rest of the World. We assume that both regions produce and consume the good, and they each produce their own specific variety of the good. The model allows for changes in three policy variables: an EU import tariff, a production subsidy or tax for EU farmers,

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and a consumption subsidy or tax on EU consumers, which are always expressed as a percentage of the price. The policy variables in the economic model are additional to the existing policy instruments already in place under the EU Common Agriculture Policy (CAP). We do not include policy changes by the RoW.

The model consists of five equations: two equations defining EU and RoW import demand, two equations defining EU and RoW export supply, and an equation specifying that difference in the price between the regions for the good produce in RoW equals the size of the EU import tariff. For example, if the EU applies a tariff on imports from the Rest of the World of t percent, this implies that the price paid by EU consumers will be t percent higher for the good compared to the price paid by consumers in the Rest of the World. Tariffs thus drive a "wedge" between the price in the RoW and the price in the EU. The derivations of the economic model are provided in Appendix A.

The economic model invokes the so-called Armington assumption, whereby domestically produced food and imported food are assumed to be imperfect substitutes. The elasticity of substitution captures how the relative demand for imports versus domestically-produced goods responds when their relative prices change. A low elasticity of substitution would imply that a large change in relative prices would not affect relative demand very much. We assume an Armington elasticity equal to 5, following Costinot et al. (2016). Interactions between the broad categories are not modelled, although these cross-category effects are likely small since cross price demand elasticities are usually a small fraction of the magnitude of own-price demand elasticities.

3.5.4. Solution Procedure and Outputs

We solve the model analytically to find unique solutions for the quantities exported from each region and the prices in each region for its domestically-produced and imported products. The model's solution for prices and quantities depends on the three policy variables and also on additional parameters such as the elasticities of supply and demand. In a standard economic analysis, one would usually be interested in the impact of a policy change on market quantities and prices. However, in this case the quantities are provided by the biophysical model, and we would like to know which policies and prices are congruent with the biophysical results with respect to quantities produced, consumed and exported from each region.

It is important that the economic model matches not only the export quantities given by the biophysical model, but also matches the quantities produced and consumed in each region. We must thus "constrain" the economic model's solution for each scenario in order to match not only the traded quantities, but also the production and consumption outcomes.

The model allows us to calculate the change in each economic policy that would be required to match the change in quantity outcome for each scenario compared to 2050 BAU. Once we have the policies needed to match the biophysical quantities, we can then use the economic model to calculate the resulting change in commodity prices in each region for each scenario compared to BAU. Once we have determined the traded quantity and the prices in each region, we can calculate the economic well-being in each region for producers and consumers of each commodity, using what is called "producer surplus" and "consumer surplus" respectively. Consumer surplus is defined as the difference between what a consumer was willing to pay for a good and the actual market price. Producer surplus is defined as the difference between what they are willing to accept and the actual market price. In a supply and demand graph, consumer surplus is the area between

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the demand curve and the price level, while producer surplus is the area between the supply curve and the price level. Given the change in revenues from the production of each commodity and assuming a multiplier effect from the JRC jobs calculator, we can also determine the impact on employment in the EU.

An important caveat to the policy results is that they should be interpreted as the market-based policies equivalent to the shifts in demand and supply generated by the biophysical models. The policies recommended by the economic model are thus only valid in the case where the patterns of food production and consumption follow the 2050 BAU and we need to obtain the alternative scenarios purely via market-oriented policies.

4. RESULTS AND DISCUSSION

4.1. The storylines

The storylines form the qualitative context (i.e. narratives) in which the quantitative outcomes from the modelling should be interpreted. The development of the storylines builds on the input gathered through the stakeholder participation process (see section 3.2), and literature data (review of recent scenario studies). The storylines were developed in an iterative manner with several points of stakeholder interactions (see section 3.3).

The storylines are formed out of the following two dimensions, which were identified by stakeholders as some of the key dimensions that determine the future food systems:

- Level of implementation of agro-ecological farming practises
- Localisation of food system (i.e. level of trade within the EU and globally)

Out of these uncertainties, five storylines are drawn up as illustrated in Figure 4. The first one, 1) **Business-as-usual**, extends the dynamics and critical aspects of current agri-food systems into the future and highlights current policy barriers to the expansion of agro-ecology. The second storyline, 2) **Agro-ecology-for-export**, depicts a future in which medium-large agricultural farms and large companies in the food processing and distribution sectors promote the agro-ecological approach as a marketing strategy. This brings out the duality between the production of added-value goods for the global markets and that of low-cost food commodities. Hence, this storyline is a case of industrial ecology, in which a weak level of agro-ecology is widely implemented, justified primarily for reasons of market demand from consumers. In the third quadrant of the scenario cross, two storylines arise, Localisation-for-protectionism and Localisation-for-sustainability. Both are based on more localised food systems and with a low level of implementation of agro-ecological practices, but for different reasons. In both these storylines, local foods, regardless of production methods, are given priority over agro-ecological farming practises. In consequence, production practises remain similar to current ones or further intensify. 3a) **Localisation-for-protectionism** do this for reasons of rising nationalism and protectionism, and calls the centrality of the EU into question and promotes further re-nationalization of agricultural policies. The 3b) **Localisation-for-sustainability** on the other hand promotes local food system not for protectionist reasons, but in an ambition to increase food system sustainability and resilience by cutting food miles and diversifying local production systems. The fourth storyline, 4) **Local-agro-ecological-food-systems,** reflects the implementation of more advanced stages of agro-ecological transition – redesign. This future might be difficult to implement given the forces that today block changes in production systems including large agri-food companies and stakeholder interests for the current structure of the CAP. A radical change would be needed to reach the future described in storyline four. The Local-agro-ecological-food-systems storyline differs from the Localisation-for-sustainability in the that the later relies more on the route of ‘sustainable intensification’ and technology for reaching sustainability, while the Local-agro-ecological-

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food-systems embraces the agro-ecological approach to food system sustainability[1]. The storylines are further described in section 4.1.1 to 4.1.5.

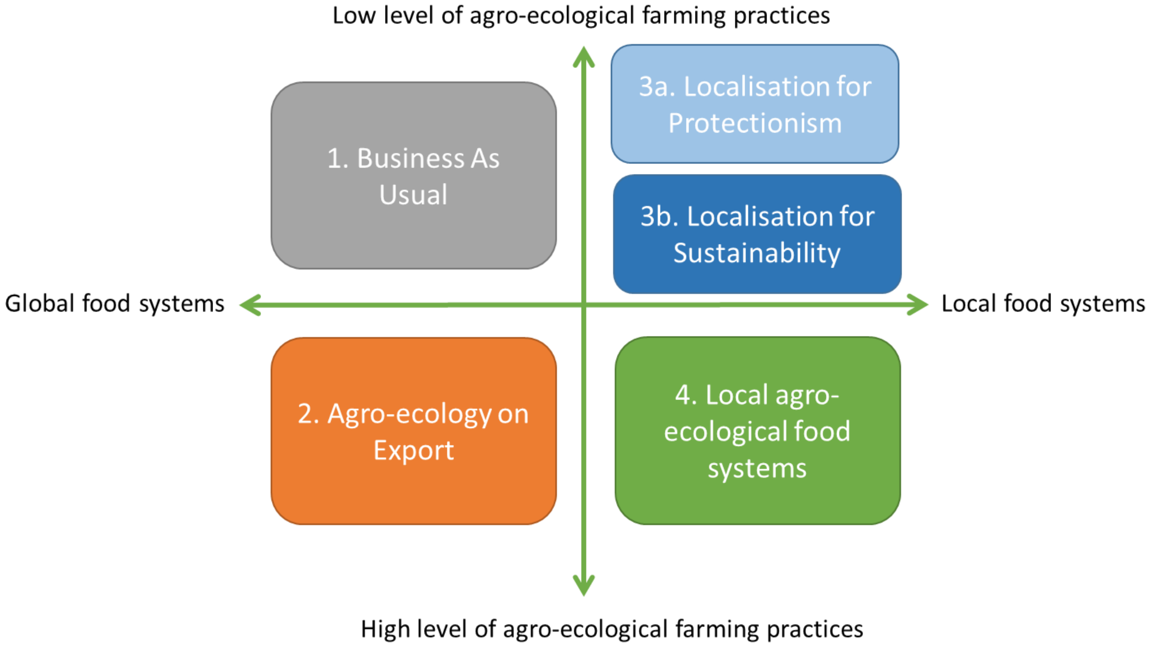

Figure 4: The UNISECO storylines.

The UNISECO narratives build on the Shared Socioeconomic Pathways (SPP) developed by the climate change community and commonly used as a basis in recent scenario development, e.g. in the latest FAO scenarios (FAO, 2019). The SSP narratives are described in O'Neill et al. (2017). The SSPs are qualitative descriptions of socio-economic future developments that can be combined with greenhouse gas concentration trajectories known as the Representative Concentration Pathways (RCPs) to be run in Integrated Assessment Models (IAMs). SSP deliberately do not give all numerical information, which gives modellers freedom of interpretation (Riahi et al., 2017). SSPs do not directly include any effect of climate change or any climate change policies, but are consistent with various RCPs.

An overview of the main characteristics of the storylines are given in Table 7.

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[11] For an explanation on the sustainable intensification' concept versus agro-ecology see e.g. Bernard et al. (2017); Godfray (2015) and Garnett et al. (2013).

Table 7. Storyline overview

	1 Business-as-usual	2 Agro-ecology for exports	3a Localisation for protectionism	3b Localisation for sustainability	4 Local agro-ecological food system
Global socio-economic context	SSP2 – Middle of the road	SSP5 - Fossil-fuelled Development – Taking the Highway	SSP3 - Regional Rivalry – A Rocky Road	SSP1 – Sustainability – Taking the Green Road	SSP1 - Sustainability – Taking the Green Road
Corresponding FAO scenario	BAU (builds on SSP2 with elements of SSP3)	BAU (builds on SSP2 with elements of SSP3)	BAU (builds on SSP2 with elements of SSP3)	TSS (builds on SSP1)	TSS (builds on SSP1)
Trade	Increased trade between member states and with non-EU countries	Even higher level of trade compared to the BAU-scenario	Decreased trade between members states and with non- EU countries, protective trade policies	Decreased trade between members states and with non- EU countries due to deliberate support for local food systems	Decreased trade between members states and with non- EU countries, protective trade policies
EU agricultural policy developments	A continuation of current policies	Continuation of current policies, but heavy focus on investments to expand exports.	A continuation of current policies, but a less centralised CAP	A continuation of current policies, but a less centralised CAP	Integrated food policy, heavy focus on local agro-ecological food systems
Type of agro-ecological practises in the EU	Mainly weak	Mainly weak	Mainly weak	Mainly weak	Mainly strong
Technological developments	SSP2: Moderate developments, tech developed in high-income countries only slowly shared	SSP5: Widespread technology optimism	SSP3: Very slow tech developments, including agricultural tech with limited tech transfer to developing countries	SSP1: Rapid tech development focussed on energy efficiency, clean energy and yield-enhancing tech for land, including in agriculture	SSP1: Rapid tech development focussed on energy efficiency, clean energy, with more nature based solutions in agriculture
Food consumption patterns (EU)	As now, develop according to current trends	As now, develop according to current trends	As now, develop according to trends, but with more local foods	Less impacting and more local, more high-tech and more local	Less impacting (reduced animal consumption), more local foods
Food waste in the EU	As now, or slightly decreased	As now, or slightly decreased	Slightly decreased	Decreased by 25-50%	Decreased by 25-50%

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4.1.1. Storyline 1: Business-as-usual

Globalised food systems - current level of implementation of agro-ecological farming practises

Global context

The SSP2 scenario, Middle of the Road, provides the overall context for this storyline. In the SSP2 scenario, it is assumed that the historical social, economic and technological trends are sustained, income growth develops unevenly and there is slow progress towards reaching sustainability goals (O'Neill et al., 2017). Technological developments are moreover modest and only slowly shared with developing countries. Low-income countries continue to experience food and water insecurity. There is a slow decrease in fossil fuel dependency and a growing energy demand (SSP2).

Food system orientation and policy landscape

Based on this, the Business-as-usual storyline describes a future in which globalisation of the EU food system continues[2]. In this system, farmers are incentivised to produce low value commodities leading to further specialisation of farming systems and regions. Trade increases both between EU member states and between the EU and global markets - specialisation in production in different regions continues (SSP2). A few multinational food industries and retailers dominate the global food market. Diets and the range of products on offer become increasingly homogeneous both within the EU and globally. Obesity levels continue to rise as does its associated health problems.

On a global level there is weak cooperation between international and national institutions, the private sector and civil society (SSP2). Access to global markets are slowly opening up for developing countries. The structure of the EU agricultural policy remains similar to the current CAP and continues to drive agriculture production towards specialised, large-scale and export-oriented agricultural production. The EU budget is somewhat decreased due to Brexit; however, most member states push for keeping the EU agricultural budget constant and rather decrease expenses in other areas. The CAP structure is similar to today; Pillar 1 has low requirements for greening. Although Pillar 2 includes support for e.g. organic production and other agro-ecological practises, variation in the implementation rate of such agro-environmental policies is large between countries and efforts uncoordinated, due to further increasing freedom for member states to allocate CAP money. Although there is an ambition at the EU-level for more agro-ecological practices (cf. The Farm to Fork Strategy) these are only half-heartedly supported by most national governments. There is a constant discussion on the ability of agro-ecology to "feed the world" and a push from large multinational agro-chemical and seed companies to implement more industrialised types of agriculture. There is only weak or no policy targeting demand in EU member states, such as taxes on unhealthy or high-impacting foods, restriction on advertisements and similar – these have been effectively counteracted by powerful lobbying groups.

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[2] The organisation of the EU food system is in this scenario well described by Therond et al. (2017) socio-economic context for farming called "Globalised commodity-based food systems" in which increasingly efficient industrial processes are used to "*produce large amounts of food that are inexpensive, convenient, safe and attractive*".

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Agricultural production and practises

As for production trends, these are assumed to continue similar to the trends described by the EU Agricultural Outlook[3] which assumes:

"• a continuation of current agricultural and trade policies;
• normal agronomic and climatic conditions;
• no market disruption".

In summary, the outlook is as follows: The utilised EU agricultural area will continue to decrease by 0.2% per year reaching 172 million ha by 2030. Although total sugar consumption decreases by 5% by 2030 because of increased health concerns, total sugar production increases by 12% by 2030, making the EU a net sugar exporter. Cereal production also increases to 341 million tons by 2030 while oilseed production will decrease due to decreased demand for biofuels. The production of feed is expected to rise due to increases in poultry, dairy and intensive beef production. Dairy exports to China are expected to increase considerably with the EU supplying 30% of the increase in dairy products mainly as cheese and skimmed milk powder. Dairy consumption increases also within the EU up to close to 900,000 tons of milk per year, mostly consumed as cheese, other processed dairy products and included in convenience foods. Milk drinking meanwhile decreases. Meat consumption per capita first slightly increases but then decreases to current levels in 2030. Beef production decreases slightly while pigmeat will increase marginally (consumption in the EU stabilises and exports increase somewhat). Poultry meat production increase by 5% until 2030.

It is assumed in this storyline that the same trends continue beyond 2030 until 2050.

Consumer interest in healthier and more sustainably produced foods including organic foods and locally produced foods increases somewhat in the EU in this storyline. However, due to lack of major public investments in, or support for the implementation of agro-ecological farming methods, these remain close to current levels on average (the share of organic farming area was 7.5% in 2018[4]) or increase slowly (reaching an average of somewhere between 10-15% of agricultural land in 2050) although with large regional variation. Certified organic products, produced using mainly weak agro-ecological practises, dominate the output from the agro-ecological farming systems in the EU; these come in the form of high-value products like wine and other alcoholic beverages, fruits and vegetables, cheese and charcuteries, jams and juice etc. sold in niche markets to high-income urban citizens, as well as cheaper bulk commodities sold in ordinary supermarkets. Diversity in crops produced in the EU are constant from current levels or somewhat further decreased (following trends in Kummu et al. (2020)).

Diets and waste

Food waste levels remain similar to current levels or decrease somewhat in countries in which waste reduction policies are implemented. Diets are not substantially changed but follow current trends.

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[3] https://ec.europa.eu/agriculture/sites/agriculture/files/markets-and-prices/medium-term-outlook/2017/2017-fullrep_en.pdf

[4] https://ec.europa.eu/eurostat/statistics-explained/index.php/Organic_farming_statistics

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4.1.2. Storyline 2: Agro-ecology for exports

Globalised food systems - high level of implementation of agro-ecological farming practises in the EU

Global context

The SSP 5 scenario, Fossil-fuelled Development – Taking the Highway, forms the basis for this storyline. In this future, focus is on competitive markets, innovation and participatory societies with the goal of reaching sustainable development through rapid technological progress and diffusion, including geo-engineering if needed (O'Neill et al., 2017). Integration of global markets continues with further removal of trade barriers, including giving access to disadvantaged actors, leading to high levels of international trade. The increased global wealth leads to the adoption of resource and energy demanding lifestyles by the growing global middle-class as developing countries follow the resource and fossil energy demanding developments of industrialised countries. Faith lies in solving the environmental consequences of this with different types of engineered technical solutions (SSP5). There is low investments into renewable energy while major investments in fossil energy continues (SSP5).

Food system orientation and policy landscape

In this storyline, food systems, as other sectors, have become increasingly globalised with high trade both within the EU and across the globe. In the EU specifically, strong support for and investment in organic farming following the goals set up in the Farm-to-Fork Strategy launched in 2020 (EC, 2020) has led to a large increase in land managed with (weak) agro-ecological practises and the total area reach somewhere between 20-50% in 2050[5]. Although the initial ambition in the Farm-to-Fork Strategy was to promote organic production to reduce environmental pressures, the main driver has gradually changed to using agro-ecological approaches (in this future interpreted as organic farming) as a means to produce high-value foods for trade between EU member states but also for exports to the newly affluent economies where a rapidly growing upper and middle class (SSP5) is demanding "clean and healthy" foods, especially foods low in pesticide residues, but there is also an increasing awareness among consumers on the risks with industrial livestock production after a series food related crisis such as zoonosis outbreaks and problems with antibiotic resistance, making them demanding organic foods.

Since most commodities are traded on the EU or global markets which require large-scale production able to deliver stable volumes to large food industries, large-scale farms dominate both the conventional and agro-ecological (here organic) farming in Europe. Infrastructure and other support for local markets are not prioritised, which further drives small-scale farmers out of business. Imports into the EU of cheap, bulk commodities like soy for feed and palm oil increase to supply low-price food to large low-income

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[5] An example of this being a plausible future development of EU agriculture is the Swedish food strategy launched in 2017 which suggests increased organic production (goal for 2030 is 30% of agricultural land), including exports, to increase rural employment and economic growth. There are also examples from Lithuania of tendencies of "industrialisation" of the organic farming sector as new very large players emerge aimed at exports to e.g. China and Australia.

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population groups in the EU. Several export-oriented policies and initiatives have been put in place in EU member states in order to meet the consumer demand for "clean and healthy" foods[6].

Products are sold on global and EU markets under third-party verified certification schemes – digital technologies (SSP5) has enabled the efficient control and management of such certification systems. Increased cooperation on global level to facilitate trade (SSP5) has led to the development of a global standard for organic production based on mainly weak agro-ecological principles (input substitution). Focus is on the ban of pesticides in organic production to prevent potential negative effects on human health. EU Quality Schemes like the PDO (Protected Designation of Origin) and PGI (Protected Geographical Indication)[7] also gain in importance and are increasingly marketed and recognised abroad. Apart from increased investments in export-oriented strategies to market organic products and other 'greener' products, the agricultural policy in the EU is similar to that of today with the majority of the money going to un-coupled area based payments with weak greening requirements. In this future, small-scale agro-ecological producers have a hard time competing with large companies that have a much greater capacity to invest heavily in promotion of 'greener' products on global markets.

According to several definitions of agro-ecology, this storyline includes an inherent inconsistency as the concept of agro-ecology includes consumption of foods produced locally i.e. large scale global trade is not part of an agro-ecological food system. However, as this is a likely development in a case in which investments in weak agro-ecological practices to produce added-value products for a global market are prioritised in combination with free trade policies, this storyline was deemed interesting and valuable.

Agricultural production and practices

Most agro-ecological farming systems resemble current mainstream organic practices and are more of the 'substitution' rather than the 'redesign' variant and policy focus mainly on the substitution of problematic inputs. It is mostly high-value crops and livestock products that are grown and marked in agro-ecological systems. For example, the recent strong trends of Spanish exports of organic products such as fruits, vegetables, wine, oil and nuts, continue due to the strong boom in demand by consumers from the central-northern countries of Europe. In addition, livestock products including milk powder, cheese and processed meat are organic products that are traded to a large extent.

Globally, EU agriculture's large share of land under agro-ecological practises is an exception, supplying a global niche market. In general, global agriculture, including the remaining EU agriculture, is dominated by input and technology intense high yielding conventional production practises (SSP5). A growing share of food is also produced in entirely industrialised systems that require little or no agricultural land for its feedstock[8].

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[6] See for example Danish goverments investments in export activities related to organic foods. https://www.foedevarestyrelsen.dk/english/SiteCollectionDocuments/Kemi%20og%20foedevarekvalitet/Oekologiplan%20Danmark_English_Print.pdfc

[7] https://ec.europa.eu/info/food-farming-fisheries/food-safety-and-quality/certification/quality-labels/quality-schemes-explained_en

[8] See for example https://solarfoods.fi/#vision

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Diets and waste

Eating patterns develop according to current projections, staying rich in meat and other resource intense food products and unhealthy foods in developed countries, with increasing meat and dairy consumption in developing countries, but with variations between income groups. Policy targeting demand to support healthy or sustainable diets is non-existent. Current developments with low-income populations struggling with diet-related diseases continue while the eating patterns of high-income populations improve somewhat partly due to technological solutions that facilitate for individuals to maintaining a healthy diet[9]. That is, a highly segmented food market is evident in this storyline in which anonymous agro-ecological products are consumed by the informed well-educated populations and exported outside the EU, while the majority consumes conventional low-quality food. Food waste levels remain similar to current levels or decrease somewhat in countries where waste reduction policies are implemented.

4.1.3. **Storyline 3a: Localisation for protectionism**

Local food systems - low level of implementation of agro-ecological practises in the EU

Global context

This scenario plays out in the future described in the SSP 3, Regional Rivalry – A Rocky Road, scenario. The world experiences a rise in nationalism and regional conflicts which pushes countries to focus on national security issues which includes trade barriers particularly in energy and agricultural markets (O'Neill et al., 2017). Countries aim to reach energy and food security goals within their own nation or region - global cooperation and trade is low (SSP3). The world is separated into several regional blocks of countries that have little exchange between them, which prevents efficient action to reach sustainability goals (SSP3). Reaching environmental sustainability goals have very low priority in this future (SSP3).

Food system orientation and policy landscape

In this storyline, we see a development in which nationally or locally produced foods, regardless of production methods, are prioritised in the EU. Investment in agro-ecological farming systems is low. To what extent localisation of food systems is achieved varies across EU member states based on the suitability of soils and climate to produce different foods, and the role of the agricultural sector in different countries, e.g. the extent of exports. In some member states, this development is a direct consequence of a continued rise in nationalism and protectionism. Some countries are experiencing discontent with EU membership and aim for greater independence (cf. Brexit). Global trade wars, reoccurring pandemics starting with the COVID-19 situation in 2020 and global political tendencies for less international cooperation and increased competition between regions (SSP3) add to the sensation of the importance of self-sufficiency in food supply. In the wake of this, some EU member states are putting policies in place

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[9] https://academic.oup.com/ajcn/article/87/5/1107/4650128

https://www.cambridge.org/core/journals/british-journal-of-nutrition/article/prospective-associations-between-socioeconomic-status-and-dietary-patterns-in-european-children-the-identification-and-prevention-of-dietary-and-lifestyleinduced-health-effects-in-children-and-infants-idefics-study/CAD97E2AC8B25B513F5D8C9797D2BCD1

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to promote more national food production based on arguments like supporting local farmers and/or reducing the dependency on imported foods e.g. to be prepared for cut-off situations due to conflicts or interruptions due to trade wars.[10] In other member states, nationalism is not as pronounced and support for continued EU-cooperation (including a large CAP budget) is maintained. However, these countries are also affected by the global political situation and strategies for food production emphasize the need for high level of self-sufficiency and independency from large food imports. Many countries look to Finland for inspiration. Finland has managed to maintain high market shares for Finnish products due to explicit goals, strategies and policy investments into strengthening the competitiveness of Finnish farming and the promotion of Finnish foods[11].

Due to the conflicting views on the role of EU institution between EU member states, the centrality of the EU CAP and the contrasting re-nationalization of agricultural policies is heavily debated. The EU has continuously been losing centralised power. However, there is still a common agricultural policy in 2050 but with a smaller budget and member states are left to make most decisions on how it is to be implemented, i.e. EU-level policies are weak. Member states keep agriculture strongly protected and financially supported. Member states manage to keep up with the international competition due to mainly protective trade policy but also by consumer demand for domestic products. On the demand side, most countries implement policies to promote consumption of local foods, e.g. requiring that public meals are "based on local traditions" and made out of domestically produced commodities and information campaigns to promote local food. Member states find creative ways to put up inter-EU trade barriers, e.g. referring to health effects etc. There is an increasing amount of publicly funded projects and initiatives to support local production, including labelling schemes[12] and policies to support short supply chains.

Agricultural production and practises

In terms of agricultural production in the EU, focus is on increased output of bulk commodities and continued growth of the agricultural sector to supply primarily the national populations, but also to achieve gains on a growing EU market through exports of surplus to other member states. An indirect effect of more local food systems is a higher diversification of food production in most countries, although within countries and at farm level production is still specialised. Although national/local food is commonly marketed as healthier and more sustainable (and perceived as such by consumers) concern for negative health or environmental outcomes is in general secondary. Local production is prioritised over implementing agro-ecological practices or other more sustainable ways of farming, which are often seen as in-efficient use of land. The influence of multinational agro-input and food companies has remained strong, but their influence has gradually decreased somewhat for a number of reasons. In countries with nationalist influences for example, people are increasingly suspicious and negative towards anything that

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[10] Example from Sweden of a municipality which might abandon their policy to purchase organic food in favour for locally produced and seasonal foods. https://www.sydsvenskan.se/2019-10-28/lunds-kommun-kan-helt-stryka-krav-pa-ekologisk-mat?redirected=1&fbclid=IwAR0KxVmGLKlvIn53HCMX8wqMVNFWO_KPpMBjWZ51mVYlv3c_v5qMmDdfV1o

[11] https://mmm.fi/en/food-and-agriculture/policy/food-policy

[12] E.g. http://euskolabel.hazi.eus/es/

relies on cooperation across countries and tend to prefer buying from national companies. New national food companies therefore arise, and existing ones are strengthened. Major investments into local food processing facilities, locally adopted machinery and production of agricultural inputs such as fertilisers, pesticides and machinery have been needed in many countries to enable local food systems. Still, power in the food chain continues to be concentrated to a few large food industries and retailers in each country. However, there is also an increased interest in local farmer markets although the volumes sold via these channels remain small. Due to the focus on national food production and nationalistic trends, local food cultures thrive in many countries.

The implementation of agro-ecological practises hence remains low or increase only slightly (maximum 15% of total agricultural area [croplands and grasslands] in 2050) to support mainly three niches of citizens; 1) those who oppose current nationalist trends and relentlessly, but not very successfully, continue to fight against environmental pollution, 2) those that use nationalist arguments for “saving our national environment” and therefore see an interest in agro-ecology[13], and 3) rich consumers in and outside the EU. Agro-ecology is limited to weak agro-ecological practises as the focus on high-yield is prevailing in the agricultural discourse. In the EU, there is a strong push to intensify national agricultural production (both in fertile and marginal areas including grasslands) with the demand for increased food output overruling objectives to reduce environmental pressures. Globally, investments in and development of agriculture is slow (SSP3).

Diets and waste

Still, most citizens continue to eat a highly environmentally impacting diet with high levels of animal products, as there are few consumer side policies put in place to steer consumption in a different direction and additionally continued investments and support for intensive livestock production. Food waste decreases slightly due to somewhat higher food prices.

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[13] Potentially this organisation is such an example http://www.ecopop.ch/de/

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4.1.4. Storyline 3b: Localisation for sustainability

Local food systems - low level of implementation of agro-ecological practises in the EU

Global context

This is an alternative storyline which emerges in the same scenario quadrant (Figure 4) as Localisation-for-protectionism, i.e. out of a combination of a high localisation of food systems and with a low level of implementation of agro-ecological practises. Compared to the previous scenario which played out in SSP3 scenario; Regional Rivalty – A Rocky Road scenario, **Localisation-for-sustainability** plays out the SSP 1 scenario: Sustainability – Taking the Green Road.[14] In the SSP 1 sustainability scenario, the growing evidence of the multi-faceted cost of inequity and environmental breakdown is pushing for the prioritisation of reaching sustainability goals, with a shift in focus from economic growth towards improvements in well-being, especially in developing countries (O'Neill et al., 2017).

Food system orientation and policy landscape

Therefore, in this storyline, local food systems do not arise for reasons of nationalism and protectionism, but rather as an outcome of a deliberate policy goal of creating sustainable and resilient food systems. Support of local food production to sustain and develop rural communities is one important socio-economic sustainability goal that is given high priority in this narrative, but other advantages with local food production also acts as important drivers. These include cutting food miles[15], closing nutrient cycling and avoiding further regional specilisation and concentration of food production which leads to water stress, loss of soil carbon, the spread of pests and negative outcomes for biodiversity. Thus, within the framework of the CAP (which design stays close to the post 2020 one), member states prioritise policies that steer towards local production systems (cf. Finland which has achieved that to a certain degree within the current CAP system).

At the same time as local food systems are promoted by global, European and national institutions, global agricultural markets are opened to developing countries (SSP1) to promote greater equity. However, due to the promotion of local and regional food systems for reaching sustainability goals, trade volumes are not substaintially increased. It is mostly high value specilised cash crops that are imported into the EU, e.g. coffee, tea, cocoa, nuts, tropical fruits etc., while the EU is a net exporter of some surplus, mainly bulk commodities (cereals, legumes, milk powder) but also some limited amounts of high value foods (wine, spirits) to regions which do not have enough agricultural land to sustain their populations (e.g. the Middle East), and to regions and consumer groups (e.g. urban middle-class) that can afford and demand these high value foods. International, as well as EU internal trade exchanges, are important for increased reslience as different regions are affected by climate change aggravated extreme events.

Agricultural practices

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[14] This scenario was added after the third workshop as several stakeholders had strong opinions on the negative framing of Localisation for protection. They argued that local food systems could be established without the negative connotations of nationalism.

[15] https://www.euractiv.com/section/agriculture-food/news/sr-agri-local-zero-kilometre-products-start-to-take-spain-by-storm/

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 773901.

The main difference between this storyline and the Local-agro-ecological-food-systems-storyline (see next section), which both include a transition to local food systems, is that the Local-agro-ecological-food-systems-storyline has a strong focus on agro-ecological food systems, including more ’nature’ based practises and redesign of agricultural systems, while this scenario focuses on the localisation aspects and relies more on technical solutions to reach sustainability i.e. it is more aligned with the ’sustainable intensification’ perspective of agriculture (Godfray, 2015). For example, in this scenario, using mineral nitrogen fertilisers produced using renewable energy[16] would be seen as a sustainable practise, while in the Local-agro-ecological-food-systems-storyline nitrogen fixation using legumes would be the preferred option. In line with the sustainable intensification perspective, further deforestation or cultivation of grassland is heaviliy regulated in this storyline. Agro-ecological practises are not increased from current levels and dominated by weak practises.

Diets and waste

A prerequisite to ’the pursuit of a sustainable and resilient localised food systems’ is a shift in diets to increased seasonality, determined by local availability of foods. Depending on location, eating patterns in the EU hence stratify. In the southern parts of Europe, climate change induced droughts drive up prices of crops and the economic viability of feeding cereals to livestock dimishes and diets hence become mainly plant-based – vegan and vegetarian diets become the norm. In the northern parts of Europe, variation in climatic conditions increase markedly, making the availability of fruits, vegetables and cereals volatile. Increased use (and dependence) on low-cost grazing on marginal lands however makes milk and ruminant meat more abundantly available. Rapid technological advancement additionally introduces an array of novel food products stemming from sources with low environmental impact, e.g. synthethic extration of protein from inedible biomass, insects and lab-cultivated foods, as well as the processing of legumes, cereals and agro-byproducts (e.g. rapeseed cake) into very meat like steaks, burgers and sausages, often indistinguishable from real meat.

High investments in health and education and an accelerated demographic transition (SSP1) result in larger shares of the global population demanding fresh and seasonal foods, which acts as a positive feedback loop on health. Supply is however continously dominated by a narrow range of foods such as wheat, maize, rice, tomatoes, apples etc. and few local and/or traditional crop types are cultivated. That is, current trends of reduced nutrient content in globally widespread crops continue which hamper some of the positive outcomes for health.

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[16] First renewable fertilisers will be on the market in 2022. https://lantmannen.com/newsroom/press-releases/lantmannen-and-yara-lead-the-way-towards-worlds-first-fossil-free-food-chain/

4.1.5. **Storyline 4: Local agro-ecological food systems**

Local food systems - high level of implementation of agro-ecological farming practises in the EU

Global context

This scenario plays out in a global context as laid out in the SSP1 scenario: Sustainability – Taking the Green Road. Here growing evidence of the multi-faceted cost of inequity and environmental breakdown is pushing for the prioritisation of reaching sustainability goals, with a shift in focus from economic growth towards improvements in well-being, especially in developing countries (O'Neill et al., 2017).

Food system orientation and policy landscape

A rapid increase in climate and environmental concerns among large population groups in the EU and fierce campaigning for stricter policies to prevent climate and environmental breakdown drive change in this storyline. The first sign of this development was seen in 2019 with the Friday for Future movements and in the 2019 election to the European parliament when the green parties increased their mandates by 40%, followed by the new Green Deal. The COVID-19 pandemic help raise the recognition of the importance of rapidly transitioning to resilient food systems. The EU level Farm-to-Fork Strategy[17] for a fair, healthy and environmentally friendly food system and the EU Biodiversity Strategy for 2030[18] launched in 2020 are hence given high priority and are successfully implemented at local level in the member states.

Globally, cooperation between national and international institutions are strengthened, and new global institutions arise to reinforce the rule of law and decrease corruption in order to effectively work towards greater sustainability on the global level (SSP1). This integrated approach to EU food security presented in the Farm-to-Fork Strategy, rather than the silo approach of separate agricultural, environmental and health policies, has been largely adopted by most member states in the year of 2028. The strategy's high ambitions for organic farming (goal of 25% of total farmland in 2030) spurs investments and interest in agro-ecological transitions to overcome multiple problems including nutrient and chemical pollution, soil erosion and soil carbon loss, high use of antibiotics and poor animal welfare and to enhance social sustainability by promotion of more small-scale and diverse farming and food production practises. As a consequence of the COVID-19 pandemic public support for factory livestock farming is heavily decreased due to their role in the development of zoonosis. Different types of alternative food systems are rapidly expanding including different types of community supported agriculture and short supply chain/direct sales online systems. To enable more localised food systems, support is also given to the establishment of small-scale processing. International markets are opened up to developing countries, but trade stays limited due to the focus on regional production (SSP1). European farmers are protected from the international competition primarily by industry and retail introducing local produce as a base criteria due to consumer demand, but also by trade agreements that implement sustainability criteria, e.g. for countries lacking tax on CO_2 emissions duties on imported goods are introduced. In combination with, and

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[17] https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal/actions-being-taken-eu/farm-fork_en

[18] https://ec.europa.eu/environment/nature/biodiversity/strategy/index_en.htm

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actually proceeding the changes in policy, many EU member states experience an explosion in bottom-up initiatives fostering agro-ecological farming practises and local food systems. Local town councils and regions play an important role here by prioritising local foods from agro-ecological systems in public procurement, providing space for marketing local food and financial support to local initiative – hence showing political leadership towards local and agro-ecological food systems. In developing countries, yield increases are accomplished thanks to rapid introduction of best practises and effective technologies, alleviating food security challenges in these regions (SSP1).

As for the CAP, it is now handled under the umbrella of the integrated food policy and has in 2050 radically changed. Most importantly, support to industrial livestock holdings have been abolished, and major investments have gone in to improving productivity of smaller agro-ecological farms and supporting transitions to agro-ecological farming. Results Based Payment Schemes and such system are largely expanded between 2030 and 2050 in most EU member states. Greater consumer awareness is achieved by coherent marketing campaigns, and with the dissemination of clear, accurate and complete information about the benefits of agro-ecological production systems for society. Programs for knowledge transfer among practitioners and producers in rural areas have also been implemented and are available for most farmers in the EU. The investment in agro-ecology is also used as a strategy to adapt to unavoidable effects of climate change. CAP Pillar 1 support is thus reformed from purely area-based to being based on several sustainability criteria. One important example is the recognition of the inefficiency of feeding human edible crops to livestock that lead to the implementation of incentives to feed ruminants more grass and forage and to the rapid rise in poultry production to level off. Intensive pork production also decreases.

Agricultural production and practices

In 2050, on average across member states, between 20-50% of land is farmed with strong agro-ecological practises serving mostly local markets. Industrial pig and poultry holdings have been drastically decreased as consumers support for such systems are heavily affected by increased awareness of animal welfare, antibiotic resistance and risk of zoonosis. Ruminant populations are not affected to the same extent as these can be incorporated into agro-ecological systems more easily. However, many intensive ruminant production systems are redesigned to be grass-based and animal numbers adjusted to local land availability. The support for local agro-ecological production has been easiest to adopt for small-scale family farms which have thrived in this policy and market environment. Despite the positive development for agro-ecology, specialised, often large scale farms, producing using conventional methods still occupy 50-80% of the land, due to their economy-of-scale advantages and sunk costs that has made it difficult for these farms to transition, and a remaining demand of cheap bulk food from large parts of the population.

An important success factor of the rapid transition to strong agro-ecology at a large scale has been food retailers' and industries' commitment and involvement in the new food strategy. Driven initially by consumer demand[19] and as a result of the societal discourse, food industries have started to work actively

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[19] Example of recent developments of consumers driving change: https://www.politico.com/news/2019/10/10/food-industry-consumer-brands-association-043892

with farmers to enable the implementation of agro-ecological schemes and then bit by bit incorporated this into their company strategies[20].

Diets and waste

The concept of locally adapted agro-ecological food systems in this storyline also includes striving for more healthy and sustainable consumption patterns. This includes a view that excess intake of “unnecessary” unhealthy foods (sugar-sweetened foods and beverages), excess consumption of livestock products, especially from animal species consuming human edible feed (i.e. pigs and poultry), and excess intake of food in general is a waste and should be prevented by powerful policy measures[21]. As should of course ordinary food waste which is reduced between 25-50% mainly as a result increased public awareness but also through a range of different policies. The Farm-to-Fork Strategy includes an initiative to make policy targeting demand and production coherently, directing the CAP support towards the production of foods desired in a healthy and sustainable diet. In order to receive CAP funding, EU member states have to develop and implement certain health promoting policy such as fiscal and social policies to promote healthy eating. As a result of the action put in place in many areas, production, consumption and waste reduction, diets are drastically changed to more sustainable, mainly plant-based, diets (see Willett et al., 2019, EAT-*Lancet* diet), although in some regions substantial amounts of beef and dairy from grass-based systems will be included in diets.

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[20] Dairy company Danone is an example of a large multinational company already promoting agro-ecology, in their case under the concept of “regenerative agriculture” https://www.danone.com/impact/planet/regenerative-agriculture.html

[21] For example, taxes on unhealthy foods and policies that steer away from using grains for animal feed.

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4.2. Biophysical modelling results

4.2.1. Land use and biomass use of storylines and trade

Land use

The five scenarios described above harvest distinct biophysical patterns in the year 2050. Based on the assumed narratives, we modelled specific variants of dimensions in the EU food system, while we assume that non-EU regions develop according the FAO business as usual business from FAO (2018b). We thus are able to compare the specific changes in biophysical indicators from changes in the European food system from the sub-national to the global scale.

Figure 5 presents an overview for the development of croplands and grasslands in the EU between 2012 and 2050 for Northern, Eastern, Southern and Western Europe. In 2012, 122 million hectares cropland (including fallows) and 97 million hectares of grasslands was used for agriculture in the EU. Eastern, Southern and Western Europe have a similar extent of croplands (32-35 Mha), and Northern Europe approximately half with 18 Mha. The latter region has, conversely, larger grassland areas (22 Mha), while the other three regions have similar (Southern Europe) or considerably smaller grassland areas.

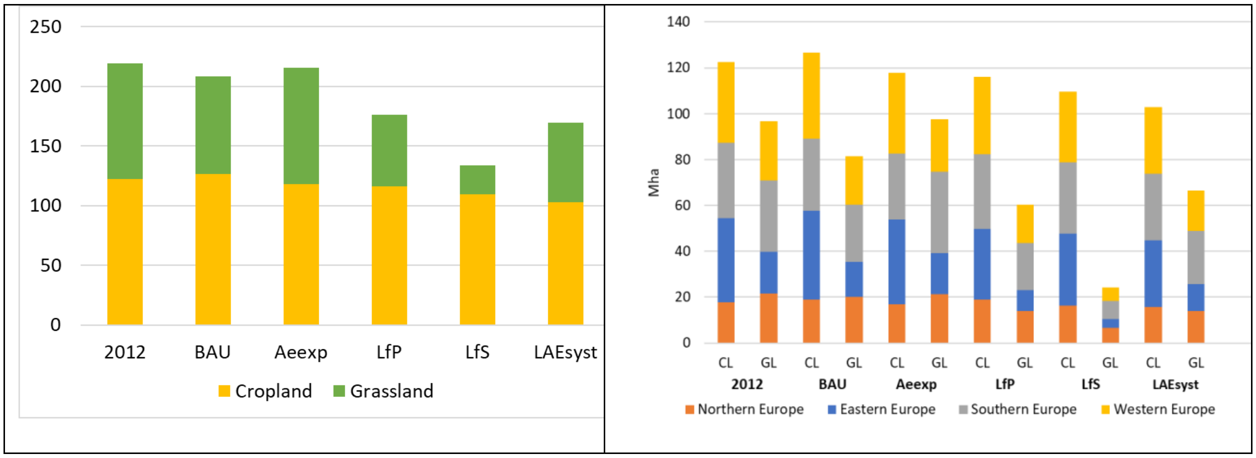

Figure 5a and 5b. Land use in million hectares (Mha) in 2012 and 2050. Figure 5a shows total land use for cropland and grassland for the EU. Figure 5b shows cropland (CL) and grassland (GL) for Northern, Eastern, Southern, and Western Europe for 2012 and for 5 scenarios for the year 2050. Eastern Europe (Bulgaria, Croatia, Czech Republic, Estonia, Hungary, Poland, Romania, Slovakia, Slovenia), Northern Europe (Denmark, Finland, Ireland, Latvia, Lithuania, Sweden), Southern Europe (Greece, Italy, Portugal, Spain, United Kingdom), Western Europe (Austria, Belgium, France, Germany, Luxembourg, Netherlands, Switzerland). Sum of all regions together is Europe. BAU=Business-as-usual, Aeexp=Agro-ecology-for-export, LfP=Localisation-for-protectionism, LfS=Localisation-for-Sustainability, LAEsyst=Local-agro-ecological-food systems

Agricultural land use in the EU decreases in nearly all scenarios in the year 2050 compared to the Business-as-usual 2012 scenario, except for the Agro-ecology-for-export scenario, where we assume that utilized cropland from 2012 remains constant. In Business-as-usual 2050, slightly less agricultural land will be needed than in 2012, but the use of cropland increases marginally. This pattern is at the one hand driven by slight population increase and dietary patterns, which is however counterbalanced by higher yields and

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better efficiencies in the conversion of primary biomass into animal-based foods. The use of grasslands is decreased due to increasing livestock efficiencies, as well as a continuation in the slightly decreasing shares of ruminant based meat and dairy products in Western diets. No shifts in the shares of organic or agro-ecological practices or trade patterns are implemented in the Business-as-usual scenario, thus the shares stay at 2012 levels.

In the Agro-ecology-for-exports scenario, cropland production is slightly reduced due to dietary changes including fewer animal products (thus, very little cropland is converted to grazing land if needed), but the EU is remaining a strong exporter for animal products, especially ruminant products. Additionally, cropland and grassland that will not be used in 2050 due to reduced domestic demand, will be used to produce agro-ecological export goods. These are high-value products such as vegetables, fruits and nuts, and their production increases domestic cropland use by 16 Mha. Additionally, since ruminant livestock production is adopting agro-ecological practices, i.e. a higher share of grass in ruminant diets, grassland use increases in the Agro-ecology-for-exports scenario. The Localization-for-protectionism (LfP) scenario shows the second highest land use for croplands in 2050, which is nearly as high as in the baseline year. Increasing self-sufficiencies are the main drivers of agricultural production in this scenario, thus agricultural production is primarily targeted towards covering domestic demand and export production in regions which were net-exporters in 2012. Thus, cropland use within the EU declines slightly compared to the baseline year, while the reduction in grassland use is larger, with a reduction of 38%. The larger reduction in grassland use reflects an expansion of cropland onto grassland in order to secure the provision of domestic demand for cropland products. Additionally, the reduction of grassland use is also a result of fewer ruminant products in the projected diets, as well as higher feed conversion efficiencies of ruminant livestock systems in 2050. In total, 176 Mha of agricultural land will be used in 2050 in the Localization-for-protectionism scenario.

The impact of the two sustainability-driven localization scenarios shows a smaller extent of future agricultural land use of 169 Mha in the Local-agro-ecological-food-systems scenario, while in the Localization-for-Sustainability scenario, land use will decrease considerably to 133 Mha in 2050. Here, different extents and levels of the implementation of agro-ecological practices strongly shape future land use (see section 3.4.3), resulting in trade-offs between demand for cropland and more extensive management.

Despite and overall declining production, Western and Southern Europe will also host the largest agricultural areas in 2050 for most scenarios, with a slight tendency of production shifts from Western towards Southern Europe. Northern Europe shows only small changes, while the land use shares of Eastern Europe increase in the Business-as-usual and Agro-ecology-for-exports scenarios. Population growth is bound to be small or even negative across the EU due to lower birth rates and emigration in the FAO population outlook (FAO, 2017). For most Eastern European countries the population growth is assumed to be negative, which leads to patterns of future cropland use in Eastern Europe that are different than in the other regions. In the Business-as-usual scenario, cropland use in Eastern Europe is slightly larger than in 2012 and in the Agro-ecology-for-exports and Localization-for-protectionism scenarios cropland use decreases only slightly compared to 2012. Here, more of the large and

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underutilized cropland potentials will be exploited to a higher extent as in the other EU regions, where underutilized agricultural lands are smaller.

Biomass production and consumption

Crop consumption for food, feed and other uses such as fibres or biofuel production are closely driven by population growth (Krausmann et al., 2013; Krausmann et al., 2008; Krausmann et al., 2012) and changing dietary patterns (i.e. levels of animal products in human diets and livestock feeding ratios). For all non-European countries, crop consumption will increase by more than 2 Gt, from 3 Gt to approximately 5.5 Gt in 2050, following the Business-as-usual projections of the FAO (FAO, 2018). In these non-European regions, dietary shifts, but more importantly, population growth will drive the total growth in agricultural biomass demand. As population growth is rather modest in Europe until 2050, shifts in dietary patterns and livestock feeding ratios is the main driver of agricultural biomass demand in the five scenarios. In the Business-as-usual scenario, crop consumption will increase strongly in Europe.

Under a Business-as-usual scenario, crop consumption in Europe will increase considerably from 386 Mt DM to 555 Mt DM. Here, increasing demand from nearly 75% of all sub-national regions in Europe is leading to the overall increase. In the Agro-ecology-for-exports and Localization-for-protectionism scenarios, crop consumption remains fairly constant in comparison to 2012, while only in the Agro-ecology-for-exports scenario, Southern Europe is considerably increasing its biomass demand, mostly driven by an increasing livestock population. Due to dietary shifts towards less animal-based food, total crop consumption from domestic livestock systems in the Localization-for-Sustainability and Local-agro-ecological-food-systems scenarios is much lower, with only half and one third in comparison to 2012, respectively. In the Local-agro-ecological-food-systems scenario, reduced cropland demand is due to more Agro-ecological practices in ruminant livestock production systems (i.e. more grassland based instead of cropland feed). Overall, crop consumption in Europe in 2050 may range from 555 Mt to only 145 Mt across all five scenarios (From 414 Mt in 2012).

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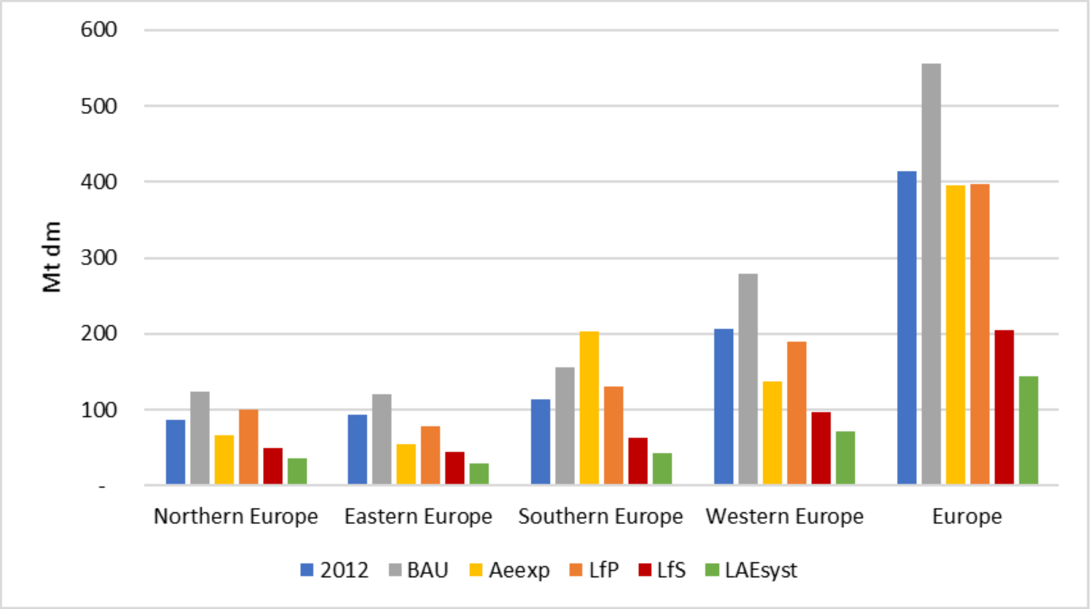

Figure 6: Total crop consumption (food, feed, other uses) in Million tonnes (Mt) dry matter for Northern, Eastern, Southern, and Western Europe for 2012 and for five scenarios for the year 2050. Please note that this figure does not show biomass consumption from grasslands. BAU=Business-as-usual, Aeexp=Agro-ecology-for-export, LfP=Localisation-for-protectionism, LfS=Localisation-for-Sustainability, LAEsyst=Local-agro-ecological-food systems

This strong decline in the consumption of cropland products in the EU is not only linked to human dietary shifts, but also to changes in animal production systems in the EU. While in the Business-as-usual, Localization-for-Sustainability and Localization-for-protectionism scenarios livestock systems remain unchanged in their structure and gain only efficiency through improved feed conversion ratios, in the Agro-ecology-for-exports and Local-agro-ecological-food-systems scenarios two important shifts are implemented. Firstly, an increasing shift towards more organic pig and poultry production systems, resulting in a lower feed conversion ratio, and secondly a massive reduction of cropland-sourced feedstuffs in ruminant systems. The latter restructuring also means strengthening the link between domestic resource endowment and livestock production as ruminant livestock is increasingly fed from grasslands. However, shifting livestock feed demand from croplands to grasslands reduces food-feed competition on croplands, but comes at the cost of grassland intensification, i.e. more biomass removal from grasslands.

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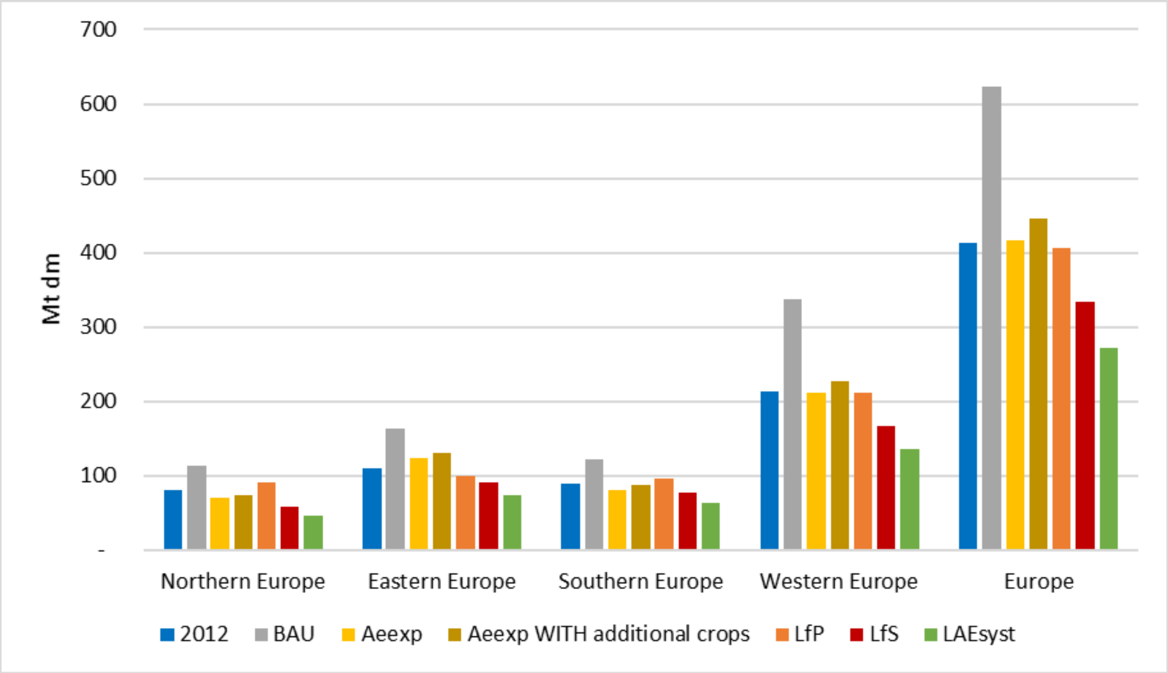

Figure 7: Total crop production (food, feed, other uses) in Million tonnes (Mt) dry matter for Northern, Eastern, Southern, and Western Europe for 2012 and for five scenarios for the year 2050. BAU=Business-as-usual, Aeexp=Agro-ecology-for-export, LfP=Localisation-for-protectionism, LfS=Localisation-for-Sustainability, LAEsyst=Local-agro-ecological-food systems

Across the five scenarios, different driving forces steer crop production patterns, with e.g. the aim to reach full autarky in the Localization-for-protectionism and Localization-for-Sustainability scenarios or high levels of food self-sufficiency combined with high levels of agro-ecological food production in the Agro-ecology-for-exports and Local-agro-ecological-food-systems scenarios. 413 Mt dry matter (DM) of cropland production in 2012 will increase considerably in the Business-as-usual scenario until 2050, with 623 Mt DM primary biomass production from cropland (Figure 7). In the Agro-ecology-for-exports and Localization-for-protectionism scenarios, cropland production slightly increases, due to massive cropland expansion for domestic food production in the Localization-for-protectionism, and the utilization of surplus agro-ecological production of free cropland in the Agro-ecology-for-exports scenario increases cropland production in the EU. There, 32 Mt DM of additional high-value products for exports outside the EU will can produced.

In all other scenarios, cropland production in the EU will decrease and fall below 350 Mt DM in the Localization-for-Sustainability and Local-agro-ecological-food-systems scenarios. This is a result of changes in diets, and in the Local-agro-ecological-food-systems scenario also due to more agro-ecological practices (i.e. lower yields). Prioritizing local self-sufficiency in the Localization-for-protectionism scenario this leads to reduced production for exports in regions with cropland larger than they need to cover domestic food and feed demand, and in the Agro-ecology-for-exports scenario it is a result of more agro-ecological practices in high-value export-oriented products such as fruits, vegetables and nuts.

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Production of animal-based products

Under the Business-as-usual assumption, the global demand and production of animal-based feed items increase from 208 Mt DM to 312 Mt DM. In all the scenarios, the development in the EU takes a different pattern (Figure 8). In Business-as-usual and Agro-ecology-for-exports scenarios, the EU is likely to produce more animal products than in the year 2012. Especially in Western Europe, by far the largest producer of beef and milk, pork, poultry and eggs, a slight increase from 27 Mt DM to 32 Mt DM is expected in the BAU scenario, similar to the developments in all other regions. In the Localization-for-Sustainability and Local-agro-ecological-food-systems scenarios, livestock production in the EU will decline even stronger, to less than one fourth of the production in 2012. These – in part – drastic reductions in livestock production are caused by re-linking livestock production systems with domestic land resources. Monogastric livestock production is shifted towards subnational regions with high cropland production potentials, which is an important measure towards closing nutrient cycles. Ruminant livestock is shifted towards regions with more grasslands, also meaning a better closure of nutrient flows.

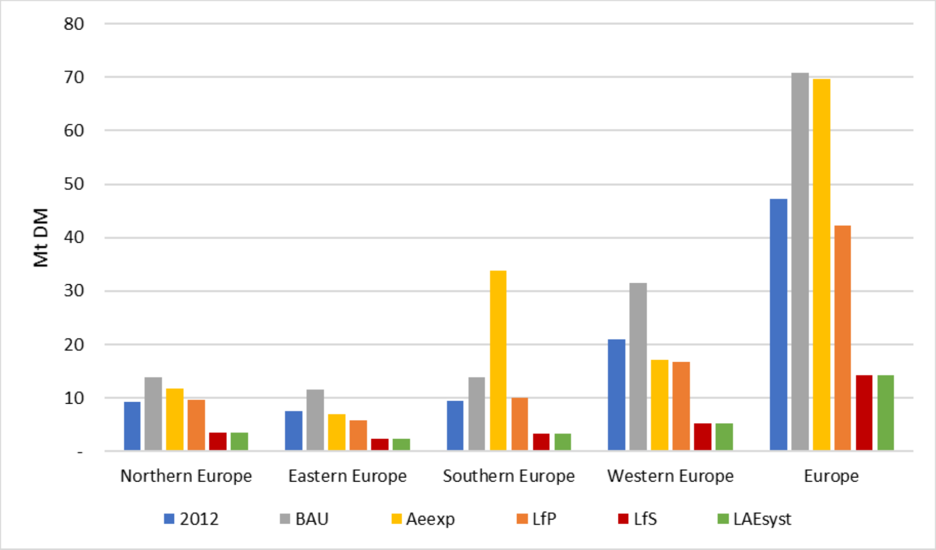

Figure 8: Production of animal-based food items in Million tonnes (Mt) dry matter for Northern, Eastern, Southern, and Western Europe for 2012 and for five scenarios for the year 2050. BAU=Business-as-usual, Aeexp=Agro-ecology-for-export, LfP=Localisation-for-protectionism, LfS=Localisation-for-Sustainability, LAEsyst=Local-agro-ecological-food systems

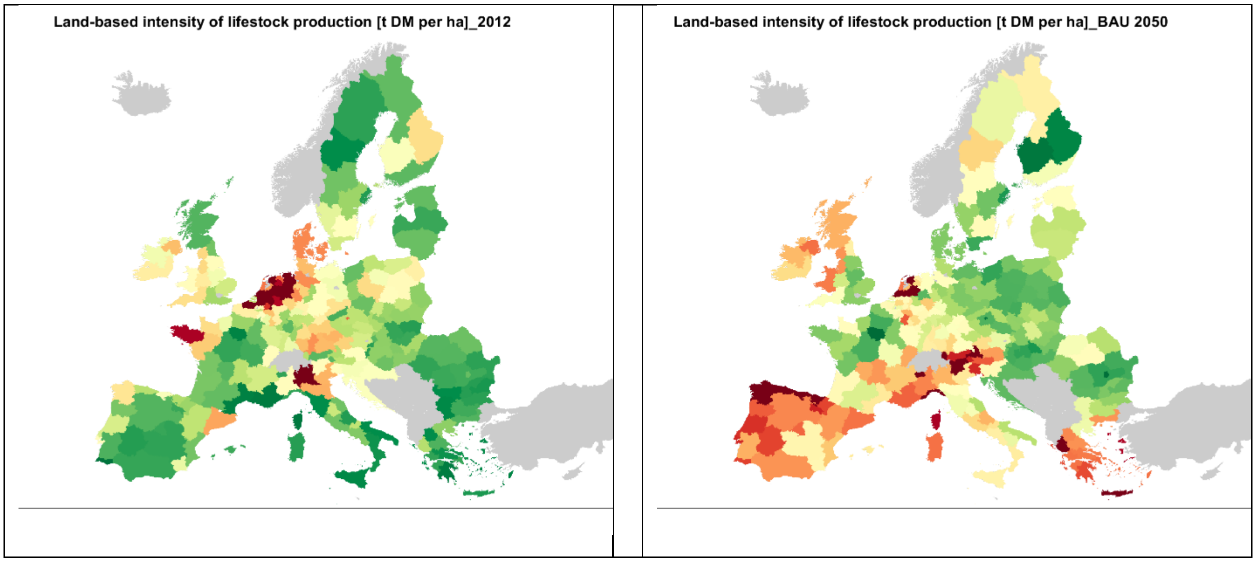

Figure 9a and 9b: Land-based intensity of livestock production in t DM per ha.

Livestock production is an important economic sector in European agriculture, but also responsible for a range of environmental impacts, such as greenhouse emissions from manure management and enteric fermentation. Figures 9a and 9b show the land-based intensity of livestock production in the EU for the baseline year and for the Business-as-usual scenario in 2050. In 2012, the Benelux countries and Western France, as well as Northern Italy show the highest intensities, and in 2050, a redistribution of livestock across the EU can be observed. There, most regions with the highest intensities reduce their livestock production, while other regions increase their production and consequently land-based intensity. Regions in Southern Europe, for example, show an increase, while the Benelux region in general shows lower values than in base year, and Eastern Europe remains at a general low level of land-based livestock intensity.

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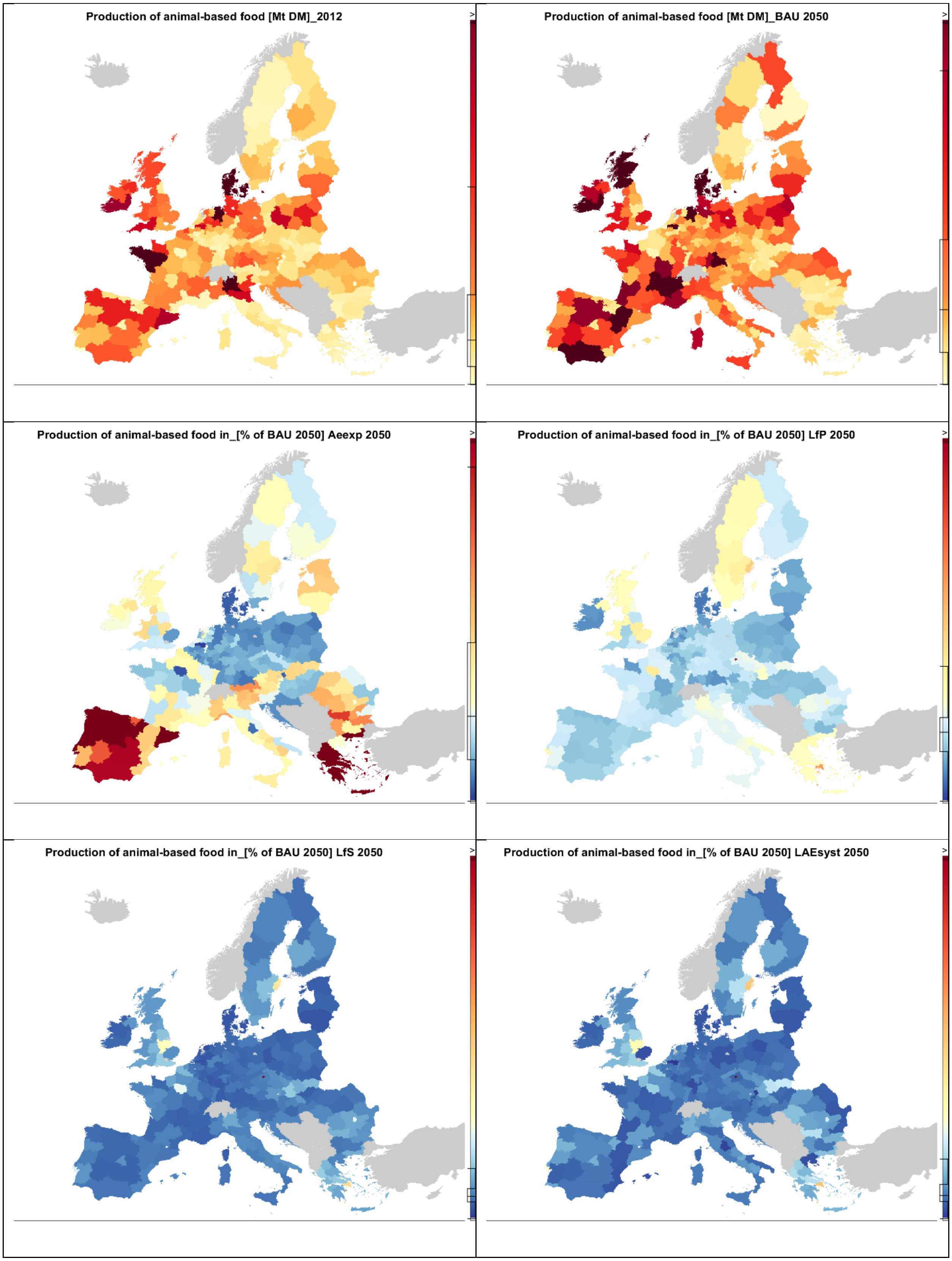

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Figures 10a-10f: Production and change in the production of animal-based food in 2012 and 2050. Figure 10a shows production in the year 2012 in Mt DM, Figure 10b shows production under a Business-as-usual scenario assumption in the year 2050 in Mt DM, Figures 10c-10f changes in production in comparison to Business-as-usual 2050 in % for the Aeexp, LfP, LfS, and LAEsyst scenario. Less animal-based food production is shown in blue, similar rates in yellow, and increasing rates in red. BAU=Business-as-usual, Aeexp=Agro-ecology-for-export, LfP=Localisation-for-protectionism, LfS=Localisation-for-Sustainability, LAEsyst=Local-agro-ecological-food systems

The production of animal-based food is an important part of the European agricultural sector, both in terms of value added, but also in terms of primary biomass requirements to feed the livestock. Figures 10a – 10f show the production of animal-based food in the base year (2012) and in the 5 scenarios for 2050. Figures 10c-10f compare the production rates for each respective scenario to the baseline scenario in the year 2050, i.e. Business-as-usual 2050. Results show that in Business-as-usual 2050, animal-based food production is in general projected to increase across the EU, with notable increases in parts of Southern and Western Europe, but also on the British Islands. In comparison, all alternative scenarios for 2050 mostly show decreasing animal-based food production, except for the Agro-ecology-for-exports scenario, where regions in Spain and Greece increase their animal-based production. In these regions, livestock production per agricultural land unit was low in the baseline year if compared to regions where the ratio of livestock production to domestic agricultural land was considerably higher, i.e. in Belgium, the Netherlands, Denmark or in Northern France. Thus, in the export-oriented scenario in 2050, the relatively large cropland areas and especially grassland potentials allow to considerably increase domestic livestock production (see Figure 10c).

Potential self-sufficiency rates and regional food systems autarky

Strengthening local food autarky is the primary goal for agricultural policies in the Localization-for-protectionism and Localization-for-Sustainability scenario, albeit this is also an important aim of agricultural policies in the Local-agro-ecological-food-systems scenario. We here assess changes in potential self-sufficiency rates for all European regions between 2012 and the respective scenarios in the year 2050. Potential self-sufficiencies show how much of the domestic food demand can be produced on current agricultural lands, and not only included biomass from cropland for direct human consumption, but also includes the feed that is required to produce the animal-based foodstuffs included in human diets. Thus, self-sufficiency rates measure the domestic demand for primary agricultural biomass to feed the human population and the domestic livestock, as well as to cover non-food demand (seed, fibers, biofuels) against the domestic agricultural land production potential, i.e. biomass production from domestic croplands and grasslands.

Potential self-sufficiency rates are calculated as the ratio of agricultural land actually available and the agricultural land required to supply the total demand for crops and agricultural products in the respective region. Self-sufficiencies are higher in regions with large shares of agricultural land and low population, and lower in urban regions with only little agricultural land. Combined cropland and grassland self-sufficiencies (i.e. potential self-sufficiencies) on the sub-national scale are developing differently in the five scenarios (Figure 11).

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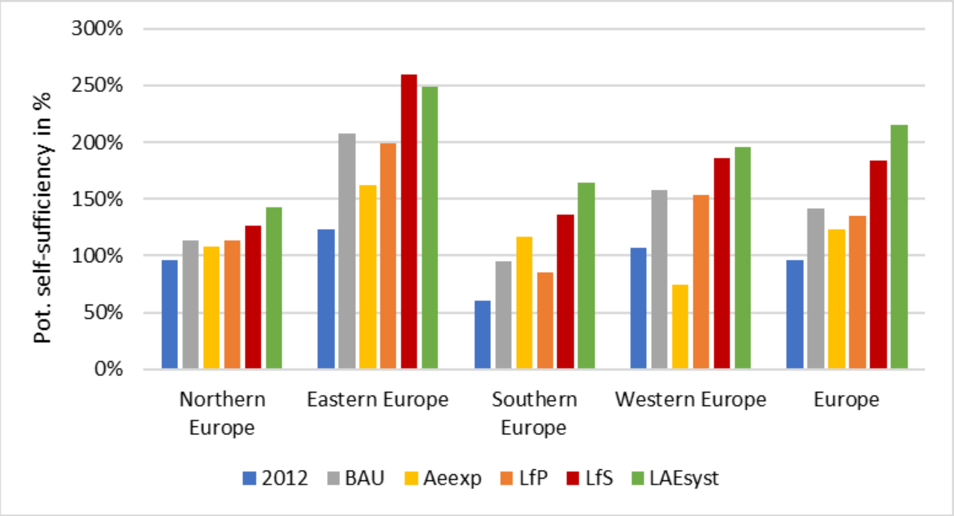
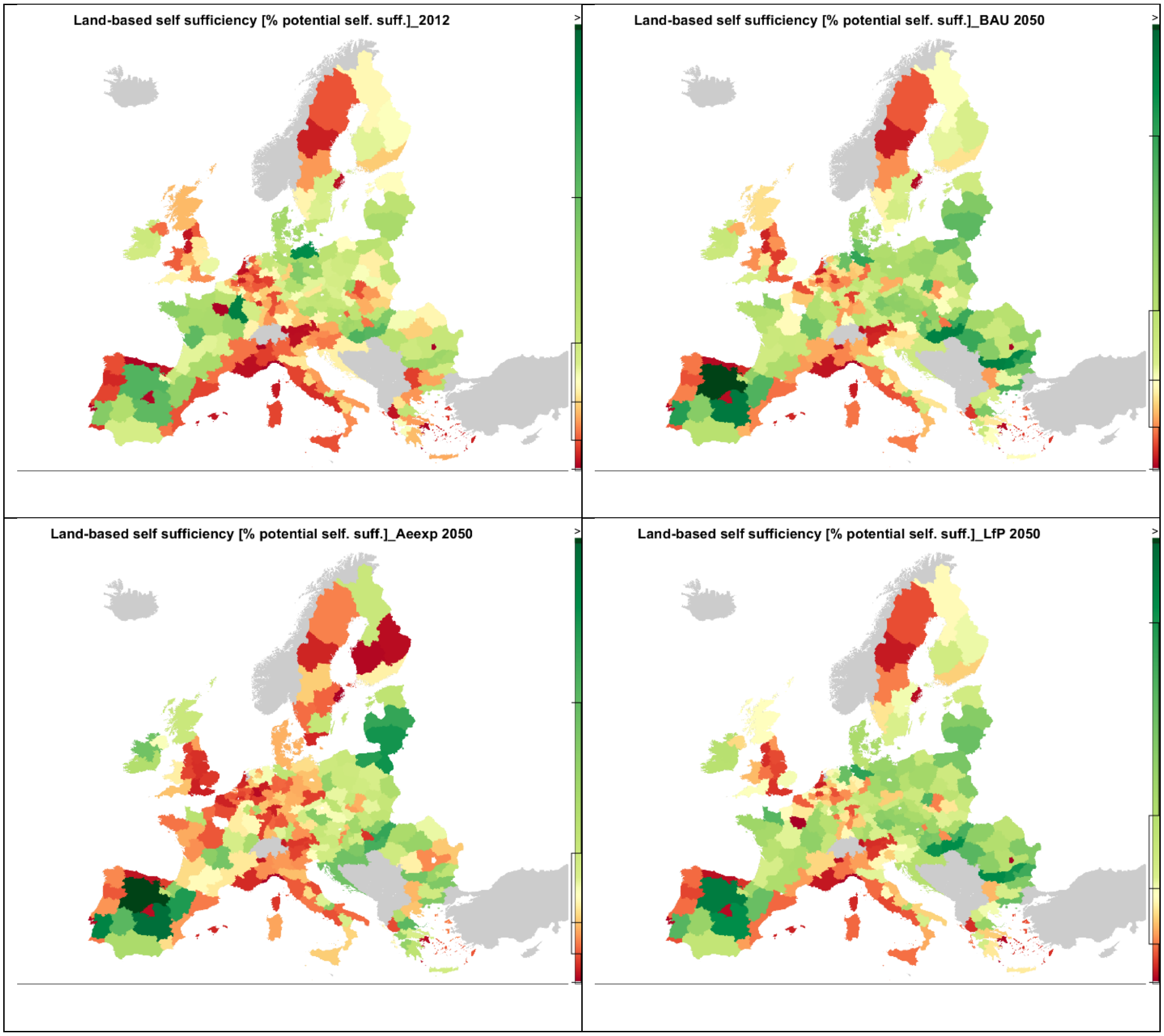


Figure 11: Potential self sufficiences in %, calculated as total demand/total supply for Northern, Eastern, Southern, Western Europe and for the whole European Union (including the UK) for 2012 and for five scenarios for the year 2050. Ratios above 100% mean that a region produces more than the inhabitants in this region consume. Please note that surplus production for exports outside the EU in the Agro-ecology-for-exports scenario is not included here. BAU=Business-as-usual, Aeexp=Agro-ecology-for-export, LfP=Localisation-for-protectionism, LfS=Localisation-for-Sustainability, LAEsyst=Local-agro-ecological-food systems

The potential self-sufficiency in the EU in 2012 was 96%, i.e. the EU cultivated nearly as much agricultural land than it needed to cover the primary biomass demand for the domestic final demand for agricultural products. Additionally, all regions except Southern Europe were close to or above full self-sufficieny in 2012. Note again that potential self-sufficiencies not only comprise croplands but also grasslands. In 2050, potential self-sufficiences will considerably increase in the Business-as-usual scenario, to 141%, meaning that the EU is assumed to produce 41% more agricultural products than its population is assumed to consume in 2050. Increasing yields and better livestock efficiences, combined with a population that is not growing in the 38 years following the base year, results in this increasing self-sufficiency. In the Agro-ecology-for-exports scenario, potential self-sufficiency is decreasing, as livestock production under agroecological practices requires more grasslands, which also does not allow to expand croplands if needed. The two localication scenarios, Localization-for-protectionism and Localization-for-Sustainability, yield increases potential self-sufficiencies, albeit often at the cost of cropland expansion into grasslands in the Localization-for-protectionism scenario, leading to carbon emissions from land use change. In the Local-agro-ecological-food-systems scenario, self-sufficiences increase, even to a higher extent than in the Localization-for-Sustainability scenario.

On the member state level, each member state only produce what the domestic population requires, except in the Agro-ecology-for-exports scenario, where production is more oriented on global demand. This leads to considerably changes in production patterns and maximum production in several regions. However, self-sufficiencies remain > 1 on a country scale, meaning that this capping of domestic production potentials are enough to cover domestic demand for agricultural biomass in across these countries in 2050. Overall, the highest self-sufficiency rates are found in the Localization-for-Sustainability and Local-agro-ecological-food-systems scenarios. Here, less animal-based products in human diets allow for higher potential self-sufficiency rates and consequently to spare domestic production potentials or to produce additional goods for exports, as envisioned in the Agro-ecology-for-exports scenario.


Land-based self sufficiency [% potential self. suff.]_2012

Land-based self sufficiency [% potential self. suff.]_BAU 2050

Land-based self sufficiency [% potential self. suff.]_Aeexp 2050

Land-based self sufficiency [% potential self. suff.]_LfP 2050

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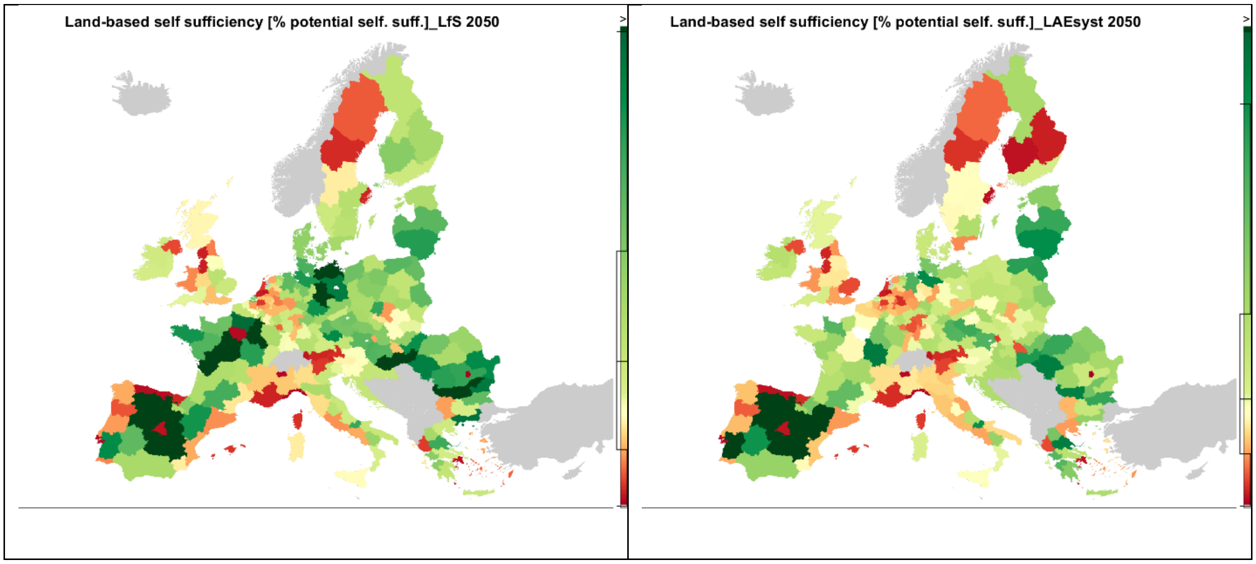
Land-based self sufficiency [% potential self. suff.]_LfS 2050

Land-based self sufficiency [% potential self. suff.]_LAEsyst 2050

Figures 12a-12f: Land-based self-sufficiencies in 2012 and 2050. Values are shown as percentage of domestic production / consumption (in primary equivalents, i.e. animal-products measured as feed demand). Shares >100% show that a region produces more than it consumes (in primary equivalents, i.e. animal-products are shown as livestock feed demand equivalents). BAU=Business-as-usual, Aeexp=Agro-ecology-for-export, LfP=Localisation-for-protectionism, LfS=Localisation-for-Sustainability, LAEsyst=Local-agro-ecological-food systems

The spatial patterns for land-based self-sufficiency show very distinct levels at the sub-national scale. In 2012, the majority of regions in the EU show positive rates, i.e. ratios above 100%. Only in Southern Europe, mostly Italy and regions along the Mediterranean cost, and some regions in Portugal and Northern Europe could not cover their domestic demand. Notably, also most regions in Belgium and individual regions in the Netherlands could not cover their demand, the latter driven by high population densities and less caused by low yields. In 2050, self-sufficiencies will mostly increase across all regions and scenarios, with the exception of the Localization-for-protectionism scenario. There, often grasslands pose a strong constraint to domestic self-sufficiency, as the primary goal of expanding croplands to meet food demand reduces grassland extents (i.e. avoiding deforestation only allows cropland expansion into grasslands). Thus, increasing self-sufficiency while maintaining current dietary patterns will lead to strong trade-offs with available grasslands to feed ruminant livestock. Adopting less meat based diets in the Localization-for-Sustainability and Local-agro-ecological-food-systems scenarios (12e and 12f) allow for higher self-sufficiencies, and thus also for additional scope to decrease overall land-use intensity or set-aside land for conservation purposes.

4.2.2. **Environmental impacts**

GHG emissions

While agro-ecological farming promises a number of positive effects on ecosystems, it is not yet clear whether there are also synergies between agro-ecology and climate-smart farming practices (see Table 1). We here assess total GHG emissions for all scenarios, while explicitly showing the effect of carbon uptake from vegetation regrowth on unused farmland if less cropland is needed in the future (see Figure 5) due to e.g. dietary shifts, less cropland feed for livestock or higher cropland yields.

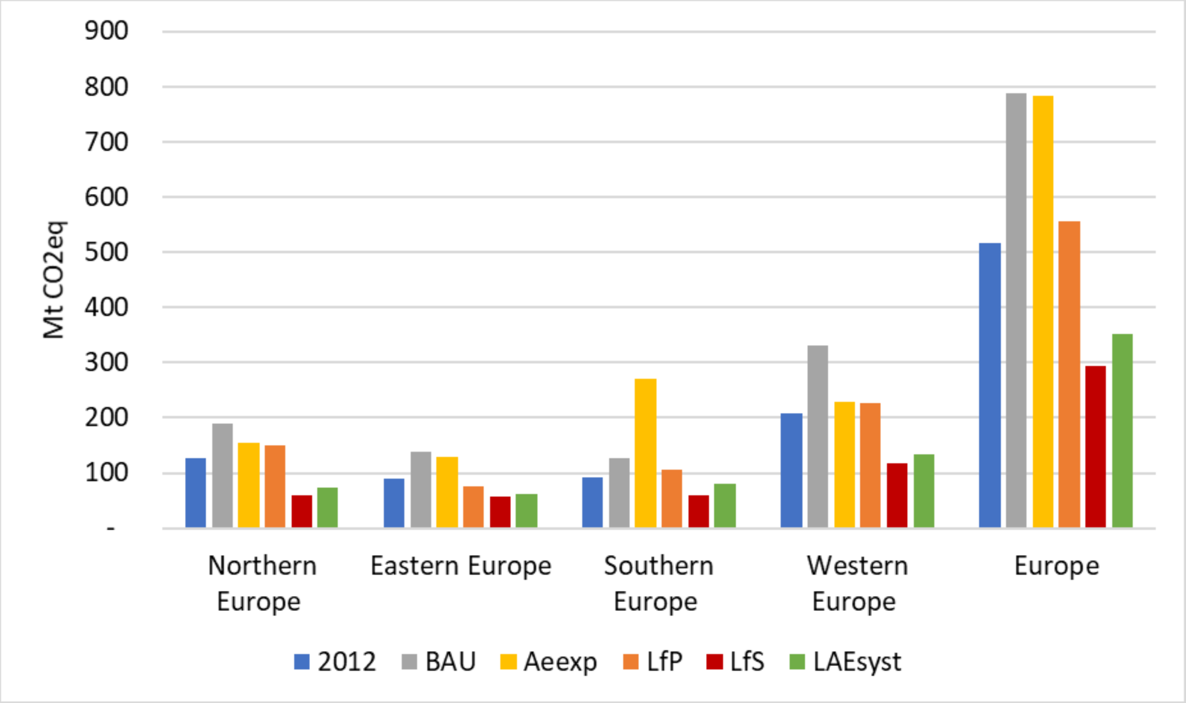

Figure 13: Total GHG emissions in million tonnes CO2 equivalents (Mt CO2eq) excluding the effect of additional carbon uptake through vegetation regrowth on unused cropland in 2050. BAU=Business-as-usual, Aeexp=Agro-ecology-for-export, LfP=Localisation-for-protectionism, LfS=Localisation-for-Sustainability, LAEsyst=Local-agro-ecological-food systems

Figure 13 displays total agricultural emissions which include emissions from agricultural management incl. upstream emissions, livestock systems and land conversion of grasslands into croplands (and vice versa). Total agricultural emissions are measured in million tonnes of CO_2-equivalents (CO_2eq) and are developing differently across the five scenarios for 2050. The highest emissions of around 787 and 783 Mt CO_2eq were found in the Business-as-usual and Agro-ecology-for-exports scenarios, the lowest emissions of 293 and 351 Mt CO_2eq in the Localization-for-Sustainability and Local-agro-ecological-food-systems scenarios, respectively. Thus, the scenarios with a medium share of the implementation of organic (25% organic production in the Localization-for-Sustainability) and agro-ecological (50% agro-ecological production in the Local-agro-ecological-food-systems) production systems have the lowest emissions, due to lower production volumes caused by reduced domestic demand, especially of livestock products. Interestingly, both agro-ecological scenarios range close to the highest and the lowest total GHG emissions in 2050, underlining the necessity of considering total production volumes and not only production technology. Additionally, the importance of the reduction of the domestic demand for livestock products is the main leverage point that allows to reach synergies between agro-ecology and less climate impact in these scenarios.

Figure 14 shows the total GHG emissions under the assumption of vegetation regrowth on abandoned croplands. In the Agro-ecology-for-exports scenario, no additional carbon sinks are created since freed up cropland is used to produce export-goods. If all cropland that is not needed to fulfil the domestic demand in Europe is used to allow for vegetation regrowth, the Localization-for-Sustainability scenario would even result in a significant net carbon sink of 522 Mt CO_2eq in 2050, and the local Agro-ecological food systems

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scenario in a net carbon sink of 204 Mt CO_2eq in 2050. The specific combination of a human diet with less meat, efficient livestock systems and a medium share of organic production systems form a climate-friendly scenario, while livestock systems are mostly kept conventional and large afforestation or vegetation regrowth needs to be implemented, with possibly negative effects of other ecosystem services.

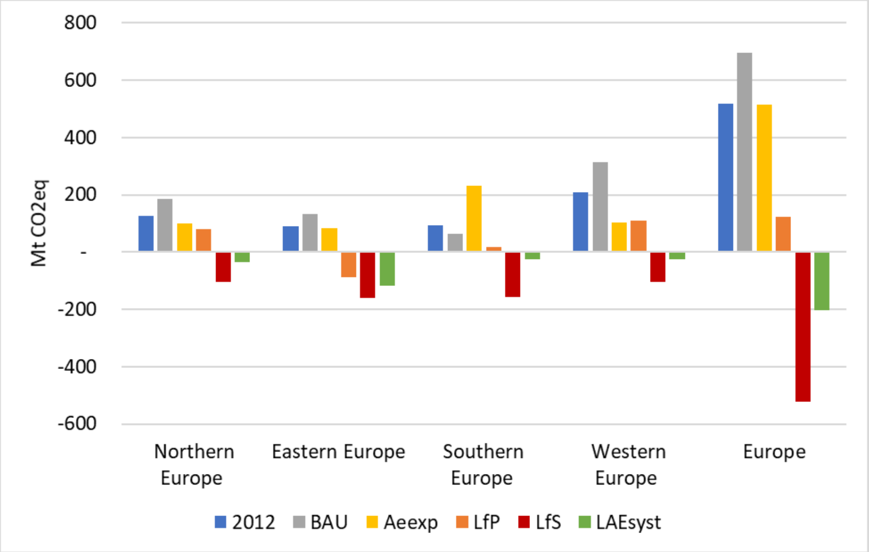

Figure 14: Total GHG emissions in million tonnes CO_2 equivalents (Mt CO_2eq) including the effect of additional carbon uptake through vegetation regrwoth on unused cropland in 2050. BAU=Business-as-usual, Aeexp=Agro-ecology-for-export, LfP=Localisation-for-protectionism, LfS=Localisation-for-Sustainability, LAEsyst=Local-agro-ecological-food systems

In general, Eastern Europe would contribute the largest share of carbon emission reductions in the Localization-for-Sustainability scenario, but would also provide a net-carbon sink in the Localization-for-protectionism and Local-agro-ecological-food-systems scenarios. Large areas of underutilized agricultural land are assumed to be abandoned and put aside as carbon sinks, probably having adverse effects on rural employment possibilities if no dedicated policy measures are undertaken, e.g. payment schemes for the provision of carbon sinks. But also in the other EU regions, the four alternative storylines (apart from the Business-as-usual 2050 scenario) provide a range of sustainability-driven and agro-ecological scenarios which are also beneficial for climate policies.

Water use

Figure 15 displays five different water use indicators. On the one hand the irrigation water use with and without adjustment for water scarcity from Pfister et al. (2011) and the Green, Blue and Grey Water Footprint from Mekonnen and Hoekstra (2010). Generally, water use is projected to increase in the BAU and less agro-ecological scenarios (LfP and Aeexp), while it largely remains on the same level as the baseline in the more agro-ecological scenarios LfS and LAEsyst. The pattern behind this are an in crease in production in BAU, and a decrease in the agroecological scenarios, with pronounced changes in production patterns if diets change, e.g. towards increased vegetable and fruit consumption that tend to have higher water use. Importantly, while the means may not change much for LfS and LAEsyst,

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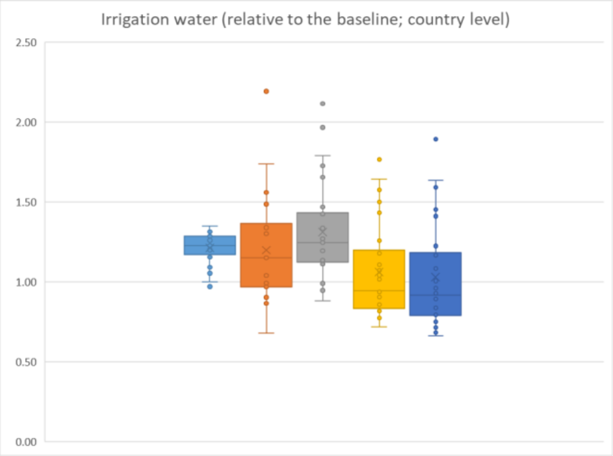
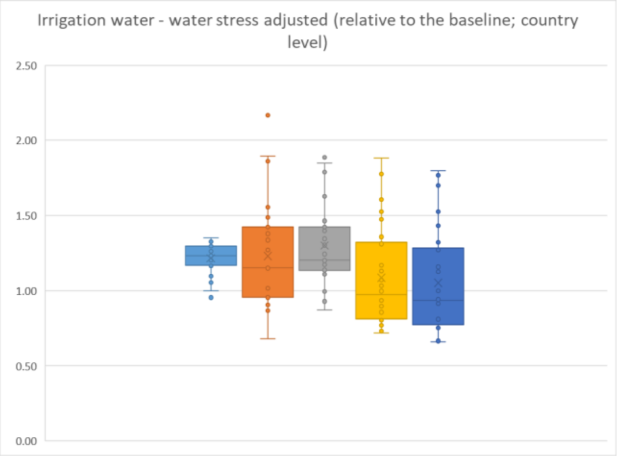
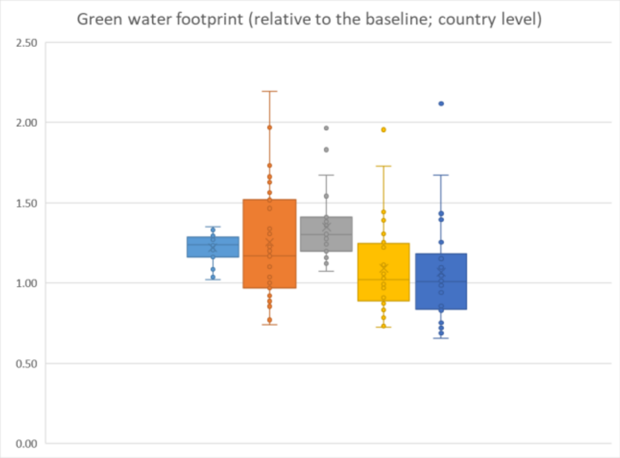
geographical spread varies considerably and some regions (e.g. southern Europe) may face considerably increase in water demand. Tis illustrates the relevance of trade-offs between different indicators in the various scenarios: while the agroecological scenarios bear much potential for improvements along many dimensions, there are cases, where impacts may be adverse (e.g. on water use, as seen here). This does not mean that these scenarios are not viable in these regions, given the gross character of the indicator used and the uncertainties in data, but it points to hot-spots that warrant particular attention to hedge against potentially adverse effects when pursuing a route towards strongly increased agroecology.



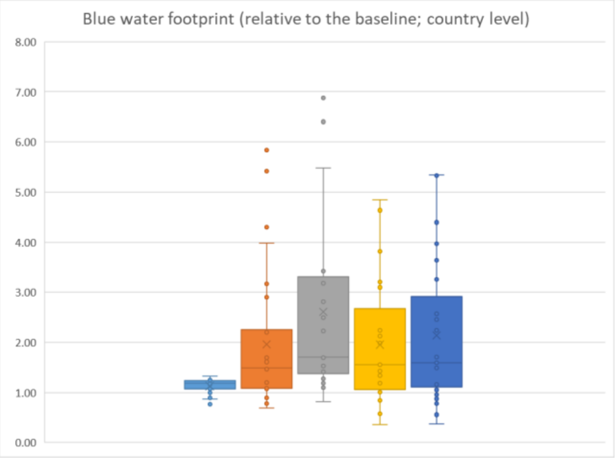
Irrigation water (relative to the baseline; country level)



Irrigation water - water stress adjusted (relative to the baseline; country level)



Green water footprint (relative to the baseline; country level)



Blue water footprint (relative to the baseline; country level)

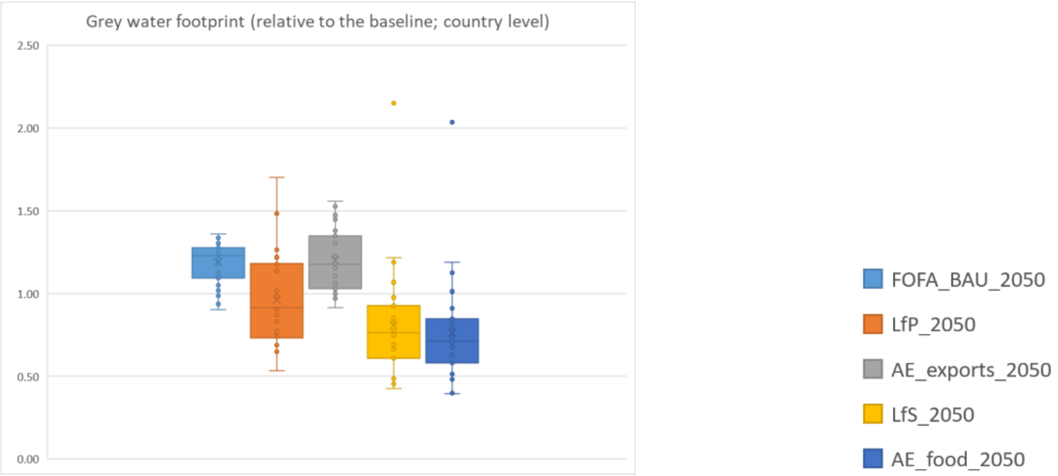


Figure 15: Different water use indicators. The data displays boxplots on country level; few outliers removed for better display of the data. This was a problem for the blue water footprint in particular, where 6 countries showed unrealistically high values. The data from Pfister et al. 2011 seem more reliable („Irrigation Water" and „Irrigation water – scarcity adjusted"); FOFA_BAU_2050=Business-as-usual, AE_exports_2050=Agro-ecology-for-export, LfP_2050=Localisation-for-protectionism, LfS_2050=Localisation-for-Sustainability, AE_food_2050=Local-agro-ecological-food systems

4.2.3. **Animal welfare**

Figures 16 and 17 display four indicators for animal welfare. This is antibiotics use, transport of living animals and heat stress (Figure 16), as well as production intensity, displayed separately for ruminants, monogastric meat and eggs (as different indicators have been used to capture this; Figure 17). The general patterns basically reflect the changes in animal numbers, given that the indicators are built on a per head impact value basis multiplied by the number of living animals. This leads to considerable improvements in most scenarios and countries (lower values reflect improvements in animal welfare). The biggest improvements are achieved for antibiotics use index, which is mainly driven by a shift from more antibiotic-intensive monogastrics to ruminants, plus an overall reduction in animal numbers, and for ruminant production intensity in LfS and LAEsyst, which is mainly due to the drastically reduced use of concentrate feed for ruminants, combined with the correspondingly lower animal numbers. As with water use, regional differences play a considerable role, but for some combinations of scenarios and indicators, (largely) unequivocal improvements are possible – while still showing considerably spread in results.

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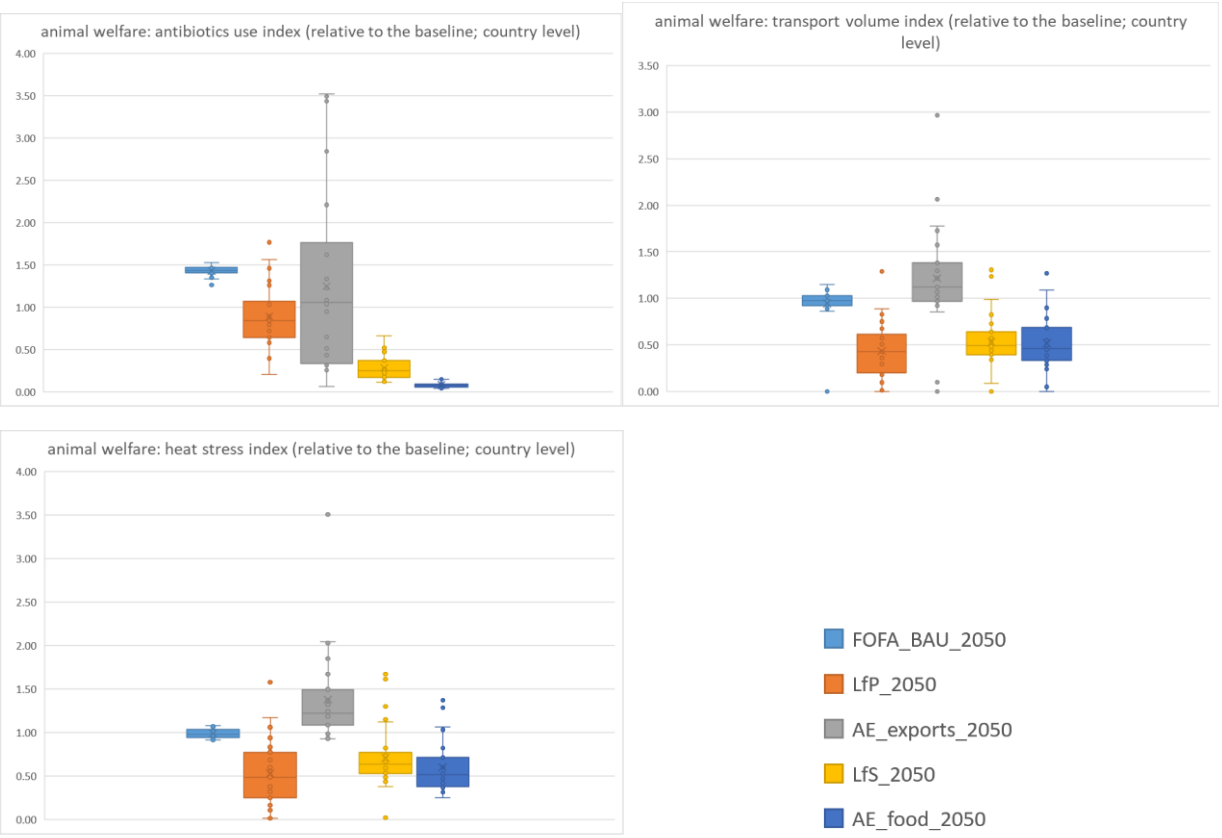
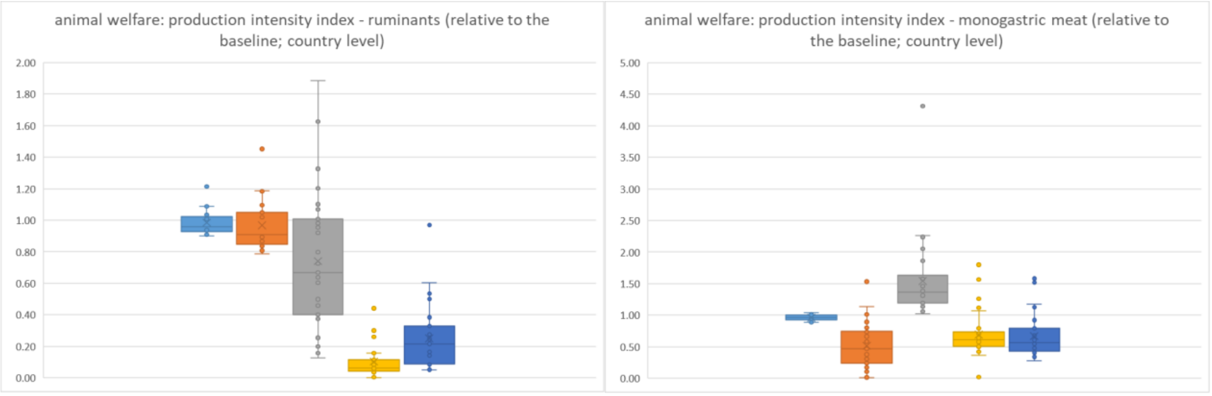


Figure 16: Different animal welfare 1: antibiotics use, transport of living animals, heat stress. The data displays boxplots on country level; FOFA_BAU_2050=Business-as-usual, AE_exports_2050=Agro-ecology-for-export, LfP_2050=Localisation-for-protectionism, LfS_2050=Localisation-for-Sustainability, AE_food_2050=Local-agro-ecological-food systems



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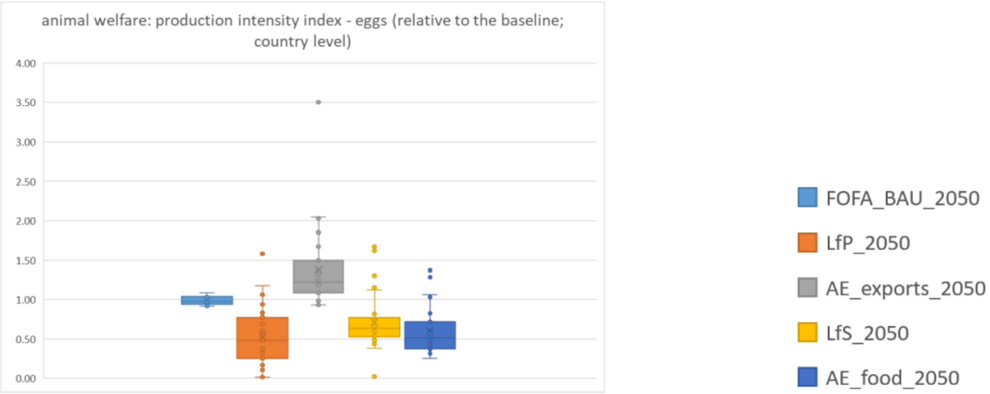

Figure 17: Different animal welfare indicators 2: intensity indicators. The data displays boxplots on country level; FOFA_BAU_2050=Business-as-usual, AE_exports_2050=Agro-ecology-for-export, LfP_2050=Localisation-for-protectionism, LfS_2050=Localisation-for-Sustainability, AE_food_2050=Local-agro-ecological-food systems

4.2.4. **Labour use and labour productivity**

Figures 18, 19 and 20 display labour use, producer value and their ration, labour productivity, for the different scenarios on country level. Generally, we can see that labour use and producer value are largely driven by the changes in production patterns in the scenarios, i.e. increased crop and decreased livestock production. Labour productivity in the livestock sector nevertheless increases, which is due to the overall changes towards less labour intensive livestock operations.

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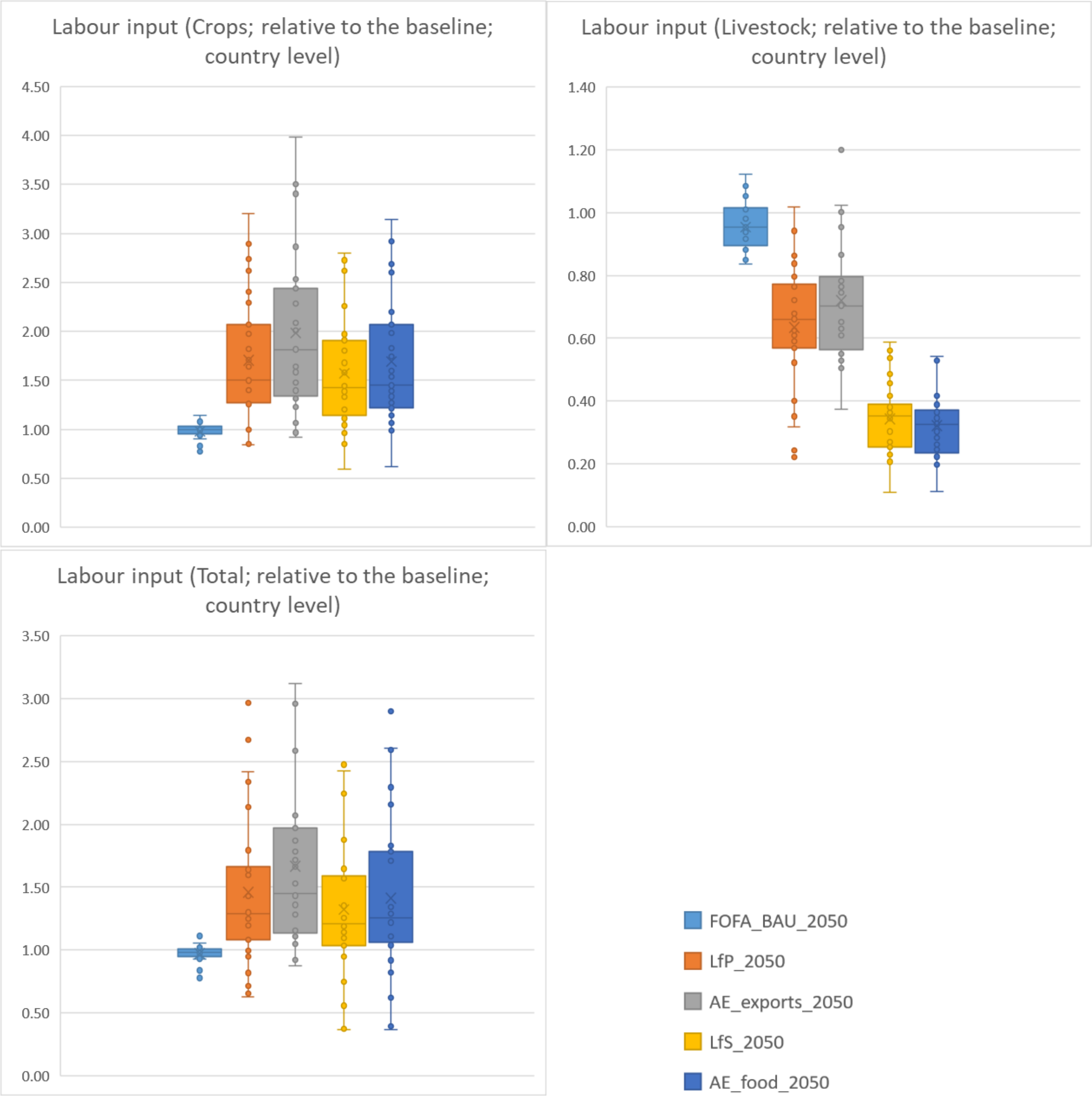

Figure 18: Labour use indicator, for crop, livestock and total production separately. The data displays boxplots on country level; FOFA_BAU_2050=Business-as-usual, AE_exports_2050=Agro-ecology-for-export, LfP_2050=Localisation-for-protectionism, LfS_2050=Localisation-for-Sustainability, AE_food_2050=Local-agro-ecological-food systems

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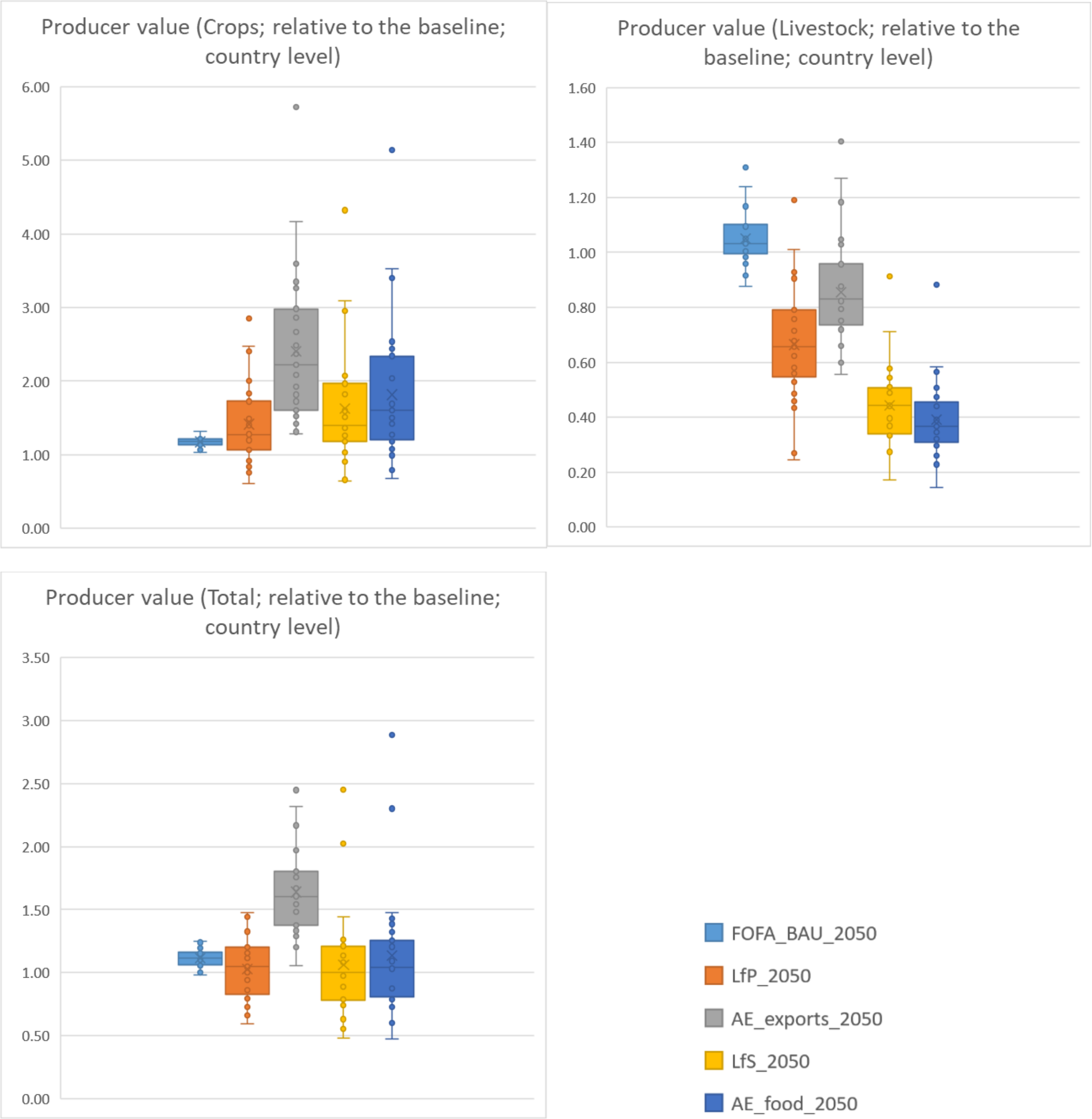
Producer value (Crops; relative to the baseline; country level)

Producer value (Livestock; relative to the baseline; country level)

Producer value (Total; relative to the baseline; country level)

Figure 19: Producer value indicator, for crop, livestock and total production separately. The data displays boxplots on country level; FOFA_BAU_2050=Business-as-usual, AE_exports_2050=Agro-ecology-for-export, LfP_2050=Localisation-for-protectionism, LfS_2050=Localisation-for-Sustainability, AE_food_2050=Local-agro-ecological-food systems

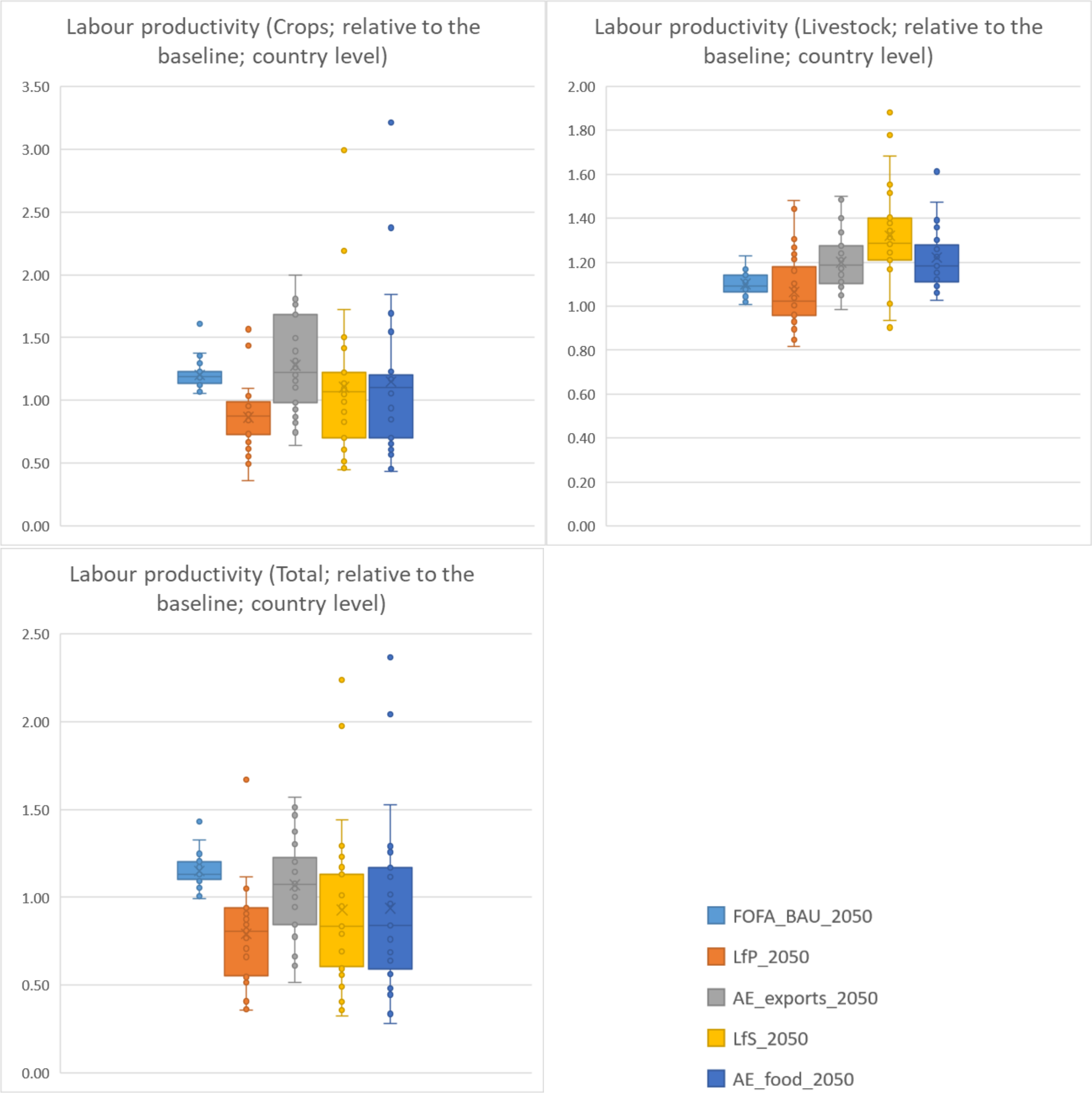

Figure 20: Labour productivity indicator, for crop, livestock and total production separately. The data displays boxplots on country level; FOFA_BAU_2050=Business-as-usual, AE_exports_2050=Agro-ecology-for-export, LfP_2050=Localisation-for-protectionism, LfS_2050=Localisation-for-Sustainability, AE_food_2050=Local-agro-ecological-food systems

4.3. Economic modelling results

We now present the results of the economic analysis. We analyze each 2050 alternative compared to the 2050 BAU.

4.3.1. Changes in Production, Consumption, Imports and Exports

The percentage changes in EU production, consumption, import and export quantities predicted by BioBaM and SOLm when moving from the 2050 BAU scenario to the Local for each scenario are summarized in Table 8. Production, consumption and trade patterns change only slightly for most commodities in the AEexport scenario, with the exception of nuts, where production and exports are predicted to increase dramatically. In contrast, EU production and consumption decreases for most commodities and traded quantities decrease for all commodities in the LfP, LfS and AEfood scenarios. Trade tends to decrease more than production and consumption in percentage terms. The biophysical models predict, for example, that cereals production and consumption decreases by 39 percent and 36 percent respectively in the LfP scenario, but imports and exports of cereals decreases by 74 percent and 83 percent respectively.

4.3.2. Required policy changes: 2050 BAU versus Agro-ecology-for-Export scenario

We enter the biophysical model's output regarding the predicted changes in production, consumption and traded quantities into the economic model in order to calculate the required change in EU policies and the resulting prices moving from the 2050 BAU to each selected scenario. The results for the Agro-ecology-for-export scenario are summarized in Table 9. The results using inelastic supply and demand based on the literature are presented in Panel A. The results assuming a more elastic supply elasticity are presented in Panel B. Finally, the results assuming a more elastic demand elasticity are given in Panel C.

The results in Panel A of Table 9 illustrate that taxes on EU production and consumption are required for most products in order to fit the production, consumption and trade quantity data using the base case supply and demand elasticities, but import tariffs are relatively unimportant (except for nuts). Import tariffs are required, with a mean of 46 percent and a median of 39 percent. The production taxes required to change production levels have a mean of 114 percent and a median of 0 percent, but there is a lot of heterogeneity based on the commodity. Consumption taxes or subsidies would be required to reach the LfP scenario, with a mean of 47 percent and a median of 1 percent.

Given the policies required to reach the Localisation-for-protectionism scenario, we can also calculate the resulting change in prices due to these policies, which are given in the last columns of Table 9, Panel A. The results suggest that prices for most domestically produced and imported food products would rise for fall only slightly in the EU, although the price of nuts would fall more sharply.

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Table 8: Change in EU production, consumption, import and export quantities, 2050 Business as Usual versus selected 2050 scenarios

	Percentage change in EU production, consumption, import and export															
	AE for exports				Local for protectionism				Local for sustainability				Local AE food systems			
	Prod	Cons	Import	Export	Prod	Cons	Import	Export	Prod	Cons	Import	Export	Prod	Cons	Import	Export
Cereals	2	1	0	5	-39	-36	-74	-83	-52	-46	-61	-80	-58	-54	-75	-88
Fruits	73	46	10	70	0	-10	-73	-82	-4	-9	-59	-70	5	-6	-73	-81
Nuts	747	128	241	2058	-38	-61	-72	-72	356	61	-16	243	415	64	-50	146
Oilcrops	-27	-12	-1	-19	79	4	-70	-63	42	-4	-55	-55	21	-23	-70	-73
Other crops	0	10	-1	-12	14	-28	-72	-91	-64	-29	-58	-82	-63	-45	-72	-92
Pulses	-26	-15	-2	-30	-36	-39	-71	-85	277	196	-53	14	303	218	-69	-19
Roots and Tubers	-43	-39	-20	-34	-61	-58	-83	-95	-58	-54	-74	-93	-56	-53	-83	-96
Sugarcrops	-42	-32	-4	-32	-23	-25	-71	-80	-68	-60	-58	-82	-67	-62	-72	-88
Vegetables	94	95	20	51	-56	-49	-77	-93	5	10	-61	-68	22	25	-74	-74
Milk	-18	-16	-4	-14	-32	-27	-72	-81	-78	-71	-63	-86	-54	-49	-74	-86
Meat	11	13	0	1	-27	-13	-71	-88	-34	-20	-57	-75	-49	-37	-71	-88
Eggs	50	51	3	3	1	7	-70	-89	3	10	-55	-75	-28	-22	-71	-90

Source: BioBaM, SOLm, authors' calculations.

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The results in Panel B of Table 9 use baseline demand elasticities, but assume a supply elasticity equal to 5, which presumes that technology will be able to adapt to the new production and consumption regime. The main impact of this assumption is that production taxes need not be as high. Import tariffs change slightly and are small for all commodities except nuts, while consumption taxes are unchanged compared to the base case. The results in Panel C of Table 9 also assume an elastic supply elasticity equal to 5, and also assumes a higher demand elasticity equal to -1, which presumes that tastes will adapt to the new scenario. The main impact of this assumption is that consumption taxes need not be as high.

4.3.3. Required policy changes: 2050 BAU versus Localisation-for-Protectionism scenario

The results for the LfP scenario are summarized in Table 10. The results in Panel A of Table 10 illustrates that taxes on EU production, consumption and imports are required for most products in order to fit the production, consumption and trade quantity data using the base case supply and demand elasticities. Import tariffs are again required, with a mean of 46 percent and a median of 39 percent. Reaching the LfP scenario would require very large decreases in production for most goods. The production taxes required to achieve lower production have a mean of 1544 percent and a median of 107 percent. Using the base case elasticities, the production taxes for some goods would not be reasonable to implement in the real world. Consumption taxes or subsidies would be required to reach the LfP scenario, with a mean of 56 percent and a median of -25 percent (a consumption subsidy).

Given the policies required to reach the Localisation-for-Protectionism scenario, we can again calculate the resulting change in prices due to these policies, which are given in the last columns of Table 10, Panel A. The results suggest that prices for most domestically produced and imported food products would rise in the EU. The mean increase in the price of EU-produced goods is 80 percent, with a 59 percent increase in price for the median good. The mean and median price increase for imports are 50 percent and 39 percent respectively.

The results in Panel B of Table 10 using a more elastic supply elasticity suggest that import tariffs change slightly and are positive for all products, while consumption taxes are unchanged compared to the base case. The results in Panel C of Table 10 also assume an elastic supply elasticity equal to 5, and also assumes a demand elasticity equal to -1. The main impact of this assumption is that consumption taxes need not be as high.

4.3.4. Required policy changes: 2050 BAU versus Localisation-for-Sustainability scenario

The results for the LfS scenario are summarized in Table 11. The results in Panel A of Table 11 illustrate that import tariffs are required, with a mean and median of 24 percent. Reaching the Localisation-for-Sustainability scenario would require very large decreases in production for most goods, even larger than the Localisation-for-Protectionism scenario. The production taxes required to achieve lower production have a mean of 2301 percent and a median of 77 percent. Again, the production taxes for some goods would not be reasonable to implement in the real world using the base case elasticities. Consumption

taxes or subsidies would be required to reach the Localisation-for-Sustainability scenario (except for Roots and Tubers and Milk), with a mean of 630 percent and a median of 1 percent.
The impacts on price reported in the last columns of Table 11, Panel A, suggest that prices for nearly all domestically produced and imported food products would rise in the EU, although the increase is not as high compared to the LfP scenario. The mean increase in the price of EU-produced goods is 39 percent, with a 40 percent increase in price for the median good. The mean and median price increase for imports are 27 percent and 23 percent respectively.

The results in Panel B of Table 11 using a more elastic supply elasticity suggest that import tariffs change slightly and are positive for all products, while consumption taxes are unchanged compared to the base case. The results in Panel C of Table 11 assuming elastic supply and demand do not change the results much compared to Panel B.

4.3.5. Required policy changes: 2050 BAU versus Local-agro-ecological-food-systems scenario

The results for the Local-agro-ecological-food-systems scenario are summarized in Table 12. The results in all panels of Table 12 illustrate that import tariffs are required, with a mean and median around 40 percent. Reaching the Local-agro-ecological-food-systems scenario would require the largest production taxes of any scenario in the analysis, with an implausible high mean of 3022 percent and a median of 145 percent. Similar to Localisation-for-Protectionism and Localisation-for-Sustainability, consumption taxes or subsidies would be required to reach the Local-agro-ecological-food-systems scenario.

The impacts on price reported in the last columns of Table 12, Panel A, suggest that prices for domestically produced and imported food products would rise in the EU, with a mean increase in the price of EU-produced good equal to 65 percent and a 58 percent increase in price for the median good. The mean and median price increase for imports are 44 percent and 39 percent respectively.

The results in Panels B and C of Table 12 using a more elastic supply elasticity suggest that import tariffs change slightly and are positive for all products, while a higher supply and demand elasticities reduce the need for high production and consumption taxes respectively.

Comparing the results in Tables 9–12, it is apparent that different elasticity assumptions have a very large impact on the required policy instruments.

4.3.6. Economic welfare, producer revenue and employment effects

The last step of the analysis is to calculate the resulting impact of the price and quantity changes on economic welfare, producer revenue and employment when moving from BAU to alternative scenarios. The results of this exercise when moving from BAU to the four selected scenarios are provided in Tables 13 and 14 assuming that the elasticity of demand equals -1 and the elasticity of supply equals 5.

The results with respect to economic welfare are described in Table 13. In the Agro-ecology-for-export scenario the quantity and price effects are generally small, which results in relatively small welfare effects that are positive or negative, depending on the commodity. In the other three scenarios, generally higher prices for the EU good and for imports, combined with lower consumption quantities, lead to lower EU consumer surplus for most crops on both domestically produced and imported commodities. EU producer surplus decreases for most commodities the three scenarios.

The impact of moving from BAU to each scenario on producer revenue and employment are summarized in Table 14. The pattern of producer revenue effects is similar in sign and magnitude to the producer surplus effects in Table 13. We calculate the employment effects based on producer revenue, and also based strictly on changes in production quantities. The revenue-based approach to calculating employment effects is relevant if price and quantity changes affect employment. However, if price changes do not affect employment then the quantity-based approach is more appropriate. Revenues and employment decline for all commodities except oilcrops and other crops. We generally find larger impacts on employment using the revenue-based approach compared to the quantity-based approach.

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Table 9: Required change in EU policies and resulting prices, 2050 BAU versus Agro-ecology-for-exports

	Import tariff (percent)	Consumption tax (percent)	Production tax (percent)	% change EU price	% change RoW price
Panel A: Base case supply and demand elasticities					
Cereals	0	-1	-7	-1	0
Fruits	-3	-19	-91	-13	-2
Nuts	-52	269	-100	-84	-52
Oilcrops	0	3	305	10	1
Other crops	0	-6	7	7	0
Pulses	1	3	282	11	1
Roots and Tubers	5	362	1005	9	5
Sugarcrops	1	39	78	9	1
Vegetables	-4	-76	-94	-8	-4
Milk	1	81	23	3	1
Meat	0	-26	-9	0	0
Eggs	-1	-70	-31	-1	-1
Panel B: Supply elasticity=5, base case demand elasticities					
Cereals	0	-1	-1	-1	0
Fruits	-3	-19	-22	-13	-2
Nuts	-53	269	-90	-84	-52
Oilcrops	1	3	17	10	1
Other crops	0	-6	7	7	0
Pulses	1	3	18	11	1
Roots and Tubers	5	362	22	9	5
Sugarcrops	1	39	22	9	1
Vegetables	-4	-76	-20	-8	-4
Milk	1	81	7	3	1
Meat	0	-26	-2	0	0
Eggs	-1	-70	-8	-1	-1
Panel C: Supply elasticity=5, demand elasticity=-1					
Cereals	0	0	-1	-1	0
Fruits	-2	-12	-22	-13	-2
Nuts	-45	154	-85	-76	-44
Oilcrops	1	3	15	8	1
Other crops	0	-3	4	4	0
Pulses	1	1	17	10	1
Roots and Tubers	5	56	22	9	5
Sugarcrops	1	22	21	9	1
Vegetables	-4	-38	-20	-8	-4
Milk	1	18	7	3	1
Meat	0	-10	-2	0	0
Eggs	-1	-32	-8	-1	-1

Source: BioBaM, SOLm, authors' calculations. See Table 2 for the base case supply and demand elasticities.

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and innovation programme under grant agreement N° 773901.

Table 10: Required change in EU policies and resulting prices, 2050 BAU versus Localisation-for-protectionism

	Import tariff (percent)	Consumption tax (percent)	Production tax (percent)	% change EU price	% change RoW price
Panel A: Base case supply and demand elasticities					
Cereals	38	21	1079	50	36
Fruits	44	-41	59	60	43
Nuts	113	-47	1449	113	113
Oilcrops	5	-49	-86	53	68
Other crops	96	-73	112	264	96
Pulses	45	-36	1013	78	45
Roots and Tubers	48	606	9504	82	43
Sugarcrops	40	-15	80	42	31
Vegetables	36	227	5061	71	36
Milk	30	103	97	39	30
Meat	28	19	103	52	28
Eggs	28	-42	56	57	28
Panel B: Supply elasticity=5, base case demand elasticities					
Cereals	37	21	66	50	36
Fruits	44	-41	60	60	43
Nuts	117	-47	134	113	113
Oilcrops	70	-49	37	53	68
Other crops	97	-73	255	264	96
Pulses	45	-36	94	78	45
Roots and Tubers	43	606	120	82	43
Sugarcrops	32	-15	50	42	31
Vegetables	36	227	102	71	36
Milk	30	103	51	39	30
Meat	28	19	62	52	28
Eggs	28	-42	57	57	28
Panel C: Supply elasticity=5, demand elasticity=-1					
Cereals	36	-9	65	49	36
Fruits	41	-39	56	56	40
Nuts	83	-38	98	80	80
Oilcrops	57	-44	27	43	54
Other crops	45	-51	95	100	43
Pulses	41	-35	86	70	41
Roots and Tubers	43	27	120	82	43
Sugarcrops	31	-19	48	41	30
Vegetables	36	12	101	70	36
Milk	30	0	50	39	30
Meat	28	-19	62	52	28
Eggs	28	-38	57	57	28

Source: BioBaM, SOLm, authors' calculations. See Table 2 for the base case supply and demand elasticities.

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Table 11: Required change in EU policies and resulting prices, 2050 BAU versus Localisation-for-Sustainability

	Import tariff (percent)	Consumption tax (percent)	Production tax (percent)	% change EU price	% change RoW price
Panel A: Base case supply and demand elasticities					
Cereals	25	85	2887	44	24
Fruits	28	-29	63	39	27
Nuts	11	32	-100	-52	11
Oilcrops	3	-39	-67	41	41
Other crops	58	-56	17872	147	58
Pulses	25	-49	-100	-4	25
Roots and Tubers	34	497	6150	70	30
Sugarcrops	27	61	301	46	21
Vegetables	22	-35	1	26	22
Milk	23	7042	486	49	22
Meat	18	83	90	32	18
Eggs	18	-35	29	33	18
Panel B: Supply elasticity=5, base case demand elasticities					
Cereals	24	85	66	44	24
Fruits	28	-29	40	39	27
Nuts	11	32	-65	-52	11
Oilcrops	43	-39	31	41	41
Other crops	59	-56	204	147	58
Pulses	25	-49	-26	-4	25
Roots and Tubers	30	497	102	70	30
Sugarcrops	21	61	83	46	21
Vegetables	22	-35	25	26	22
Milk	22	7042	103	49	22
Meat	18	83	43	32	18
Eggs	18	-35	32	33	18
Panel C: Supply elasticity=5, demand elasticity=-1					
Cereals	24	16	65	43	24
Fruits	26	-28	38	37	26
Nuts	9	15	-59	-44	8
Oilcrops	35	-35	24	33	34
Other crops	28	-33	100	63	28
Pulses	23	-42	-26	-3	23
Roots and Tubers	30	26	102	70	30
Sugarcrops	21	23	81	44	20
Vegetables	22	-26	25	26	22
Milk	22	190	103	49	22
Meat	18	4	43	32	18
Eggs	18	-28	32	33	18

Source: BioBaM, SOLm, authors' calculations. See Table 2 for the base case supply and demand elasticities.

Table 12: Required change in EU policies and resulting prices, 2050 BAU versus Local-agro-ecological-food-systems

	Import tariff (percent)	Consumption tax (percent)	Production tax (percent)	% change EU price	% change RoW price
Panel A: Base case supply and demand elasticities					
Cereals	39	94	5815	63	37
Fruits	43	-42	26	57	42
Nuts	52	3	-100	-42	52
Oilcrops	5	-49	-19	77	69
Other crops	96	-71	23980	281	96
Pulses	42	-56	-100	7	42
Roots and Tubers	47	387	5887	87	42
Sugarcrops	42	42	325	60	32
Vegetables	33	-55	-42	32	32
Milk	31	547	200	49	31
Meat	28	189	178	54	28
Eggs	29	50	112	58	29
Panel B: Supply elasticity=5, base case demand elasticities					
Cereals	37	94	93	63	37
Fruits	43	-42	55	57	42
Nuts	54	3	-58	-42	52
Oilcrops	72	-49	70	77	69
Other crops	98	-71	365	281	96
Pulses	42	-56	-19	7	42
Roots and Tubers	43	387	121	87	42
Sugarcrops	33	42	99	60	32
Vegetables	33	-55	27	32	32
Milk	31	547	74	49	31
Meat	28	189	75	54	28
Eggs	29	50	69	58	29
Panel C: Supply elasticity=5, demand elasticity=-1					
Cereals	36	12	92	62	36
Fruits	41	-39	52	54	40
Nuts	40	-6	-53	-34	39
Oilcrops	58	-43	55	61	55
Other crops	45	-47	150	105	44
Pulses	39	-49	-20	6	38
Roots and Tubers	42	11	121	87	42
Sugarcrops	32	11	96	58	31
Vegetables	32	-38	27	32	32
Milk	31	37	74	49	31
Meat	28	11	75	53	28
Eggs	29	-16	69	58	29

Source: BioBaM, SOLm, authors' calculations. See Table 2 for the base case supply and demand elasticities.

Table 13: Economic welfare effects, 2050 Business as Usual versus selected 2050 scenarios

	Change in economic surplus in EU, EUR billions											
	AE for exports			Local for protectionism			Local for sustainability			Local AE food systems		
	Consumer surplus EU good	Consumer surplus imports	EU producer surplus	Consumer surplus EU good	Consumer surplus imports	EU producer surplus	Consumer surplus EU good	Consumer surplus imports	EU producer surplus	Consumer surplus EU good	Consumer surplus imports	EU producer surplus
Cereals	1.1	0.0	0.5	-30.1	-5.9	-10.5	-41.7	-3.6	-13.0	-44.9	-6.0	-13.8
Fruits	18.5	0.5	8.5	2.4	-11.5	0.0	0.9	-6.8	-0.5	3.9	-11.4	0.7
Nuts	1.0	2.0	1.0	-0.1	-2.1	-0.1	0.8	-0.2	0.6	0.9	-1.0	0.7
Oilcrops	-13.7	-0.9	-9.0	44.2	-125.9	25.5	25.6	-73.7	14.1	15.1	-128.3	7.0
Other crops	0.0	-0.2	0.0	0.1	-48.6	0.2	-0.4	-28.8	-0.9	-0.4	-48.7	-0.9
Pulses	-0.6	0.0	-0.4	-0.6	-2.0	-0.5	6.3	-1.0	3.4	6.8	-1.8	3.6
Roots and Tubers	-11.8	0.0	-2.6	-14.3	-0.3	-3.3	-14.0	-0.2	-3.2	-13.7	-0.3	-3.2
Sugarcrops	-4.7	-0.1	-1.8	-2.6	-2.3	-1.0	-5.8	-1.5	-2.3	-5.8	-2.4	-2.3
Vegetables	59.3	0.2	14.6	-31.1	-2.0	-8.0	6.0	-1.1	0.9	17.4	-1.8	3.6
Milk	-23.3	0.0	-5.1	-35.9	-0.4	-9.0	-48.3	-0.3	-10.3	-59.8	-0.5	-13.6
Meat	11.2	0.0	2.5	-18.4	-0.8	-5.9	-25.5	-0.5	-7.2	-36.9	-0.8	-9.7
Eggs	9.5	0.0	2.0	0.7	-0.1	0.0	1.0	-0.1	0.1	-4.8	-0.1	-1.1

Source: BioBaM, SOLm, authors' calculations. Results assuming supply elasticity=5 and demand elasticity=-1.

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Table 14: Producer revenue and employment effects, 2050 Business as Usual versus selected 2050 scenarios

		Change in producer revenue (billion EUR) and change in employment (millions)											
		AE for exports			Local for protectionism			Local for sustainability			Local AE food systems		
	Emp. per million EUR	Prod. Rev. (billion EUR)	Emp., millions (Rev. -based)	Emp., millions (Quant. -based)	Prod. Rev. (billion EUR)	Emp., millions (Rev. -based)	Emp., millions (Quant. -based)	Prod. Rev. (billion EUR)	Emp., millions (Rev. -based)	Emp., millions (Quant. -based)	Prod. Rev. (billion EUR)	Emp., millions (Rev. -based)	Emp., millions (Quant. -based)
Cereals	22	2.7	0.1	0.0	-76.7	-1.7	-1.5	-108.1	-2.4	-108.1	-124.8	-2.7	-2.7
Fruits	19	43.5	0.8	0.6	0.1	0.0	0.0	-2.8	-0.1	-2.8	3.9	0.1	0.1
Nuts	19	4.1	0.1	0.0	-0.6	0.0	0.0	2.7	0.1	2.7	2.9	0.1	0.0
Oilcrops	24	-60.7	-1.5	-1.3	129.9	3.1	2.4	76.1	1.8	76.1	39.5	0.9	0.8
Other crops	73	0.0	0.0	0.0	1.4	0.1	0.1	-9.1	-0.7	-9.1	-8.9	-0.6	-0.6
Pulses	73	-2.6	-0.2	-0.2	-3.7	-0.3	-0.2	14.9	1.1	14.9	15.8	1.2	0.8
Roots and Tubers	74	-19.9	-1.5	-1.4	-31.6	-2.3	-2.3	-29.2	-2.2	-29.2	-28.3	-2.1	-2.0
Sugarcrops	61	-13.9	-0.8	-0.8	-6.9	-0.4	-0.4	-25.5	-1.6	-25.5	-24.8	-1.5	-1.5
Vegetables	17	73.1	1.2	0.9	-69.9	-1.2	-1.1	5.3	0.1	5.3	20.2	0.3	0.3
Milk	21	-32.7	-0.7	-0.6	-62.6	-1.3	-1.2	-195.4	-4.1	-195.4	-116.7	-2.5	-2.3
Meat	30	14.4	0.4	0.4	-40.0	-1.2	-1.1	-50.4	-1.5	-50.4	-77.8	-2.3	-2.2
Eggs	21	10.7	0.2	0.2	0.1	0.0	0.0	0.7	0.0	0.7	-7.6	-0.2	-0.1

Source: BioBaM, SOLm, authors' calculations. Results assuming supply elasticity=5 and demand elasticity=-1.

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5. CONCLUSIONS

From this first assessment of five different scenarios for the EU, we derive several preliminary conclusions. The results will be analysed further and more results will be added and analysed in the following months, also including an intermediate assessment in 2030 and including an analysis of further indicators for environmental and social aspects, as well as certain economic assessments.

First, the various scenarios show that a decrease in land use, land use intensity, water use, adverse animal welfare impacts and GHG emissions can be achieved without compromising food security and regional food self-sufficiencies. Regional differentiation is however important to identify hotspot regions where specific actions within such broad strategies as described in the scenarios may be needed to curb local stronger adverse effects.

Second, the drivers behind sustainability improvements are an overall reduction of the size of the food system measured in total land use and in particular in total biomass production and biomass production from animals in particular. This is achieved by combining consumption-side measures that mainly aim at realising less animal source food in diets, and production side measures, that aim at shifting from crop-based to roughage-based animal production on the one hand (an agro-ecological systems re-design), and at distributing the different production activities to the regions where they can be done most efficiently, as well as efficiency increases in general (expected yield increases, etc.). Re-balancing agricultural land potential and livestock production, an important measure of agro-ecological transitions brought up during stakeholder-meetings within UNISECO, is possible within scenarios that reach less environmental impacts than if the structure of the current production patterns remain in 2050.

Third, the choice of the production systems itself – agro-ecological, organic, or conventional in this case – is less relevant for GHG improvements than the reduction of the quantities produced. This is for example illustrated with the Agro-ecology-for-export scenario contrasted with the Local-agro-ecological-systems scenario, where the former has considerable emissions and volumes, albeit being an agro-ecological scenario, while the later performs well regarding emissions – and also being an agro-ecological scenario.

Fourth, if demand and supply side measures are applied together and in close coordination, trade-offs between less intensive agricultural production and putting land aside for nature-based climate solutions are possible. Thus, a more sustainable and less intensive form of agricultural production that implements agro-ecological practices does not necessarily come at a high price for climate-change mitigation if the size of the total food system is reduced.

Fifth, labour input rather increases in the scenarios and labour productivity does largely not decrease. Also here, the spread between regions is large and in some regions, strong reduction in labour use may arise, while in others strong increases may be seen. Furthermore, the already identified strong shifts in production systems are also behind these patterns, i.e. a shift from livestock to crop production and within livestock, from monogastrics to ruminants. Thus, as for the environmental indicators above, it is important to implement complementary measures to hedge against adverse impacts in hot-spot regions.

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Overall, the biophysical model output suggests that moving from the 2050 BAU to the Localisation-for-protectionism, Local-for-sustainability and Local-agro-ecological-food-systems scenarios generally imply very large decreases in the production and consumption of most food commodities, and even larger decreases in trade. The economic model finds that a combination of EU production taxes, EU consumption taxes, and EU import tariffs are sufficient to generate the quantity outcomes from the biophysical model. In general, reaching these three scenarios is equivalent to implementing a very strong policy intervention, especially with respect to taxes on EU production. In contrast, the Agro-ecology-for-export scenario is equivalent to a relatively more modest policy intervention due to its relatively small impacts on quantities produced, consumed, and traded.

The magnitude of the policies that would bring about these sweeping changes in production and consumption depends crucially on the elasticities of demand and supply, which are based on our best guess of the sensitivity of future food supply and demand to future price changes. If the supply of food is more sensitive to price changes, then the production taxes do not need to be so large in order to reach any scenario.

Most of the results of from the economic model seem reasonable in the sense that large changes in quantities will require large policy measures, which we see on the production taxes in particular. Since the model calculates everything in percentage terms, the percentage taxes become economically implausible for some products. As with many economic models, the results become less trustworthy the further one departs from the initial equilibrium.

A purely economic model may have come to different conclusions in some cases compared to applying an economic model to quantity output from a biophysical model. One example is the policy solution for cereals, which prescribes a large production subsidy to reach the Localisation-for-protectionism, Local-for-sustainability and Local-agro-ecological-food-systems. An economic model yielding a decrease in meat production would likely have allowed for more EU exports of cereals in response to a decrease in cereal demand, making such large production taxes unnecessary. However, the output from the biophysical model in these three scenarios predicts a decrease in EU cereal exports. This is one example of the possible limitations of not fully integrating biophysical and economic models. However, the results of the economic model are instructive in that they provide some insight on how the output from the biophysical models would affect prices and economic welfare.

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