Key dilemmas on future land use for agriculture, forestry and nature in the EU

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Foreword

The Mansholt Lecture is an annual event held in Brussels, organised by Wageningen University & Research (WUR). Its purpose is to inspire European policymakers and stakeholders on critical societal issues, particularly those related to sustainable agri-food systems and the living environment. The lectures draw from the knowledge and insights of WUR researchers, highlighting how they can offer sustainable pathways to some of the world's most pressing challenges.

Since the start of the European Union (EU) in 1957, agriculture has been a key element in the integration of the economies of the Member States and one of the policy areas where the creation of a common policy has progressed furthest. European agriculture commissioner Sicco Mansholt, after whom this lecture is named, played an important role in developing the Common Agricultural Policy (CAP). Since the 1950s, the context of agriculture has changed significantly and with the expansion of the Union, the diversity of perspectives within the EU increased. Not only on challenges, but also around ideas on how agriculture and forestry should or could further develop to match supply to our future food and non-food demand.

The Mansholt Lecture 2023 presented an optimistic vision for achieving a climate-resilient and nature-positive future for Europe by 2120. In outlining this journey, we emphasised the crucial role of harnessing the power of human imagination. This year, the Mansholt 2024 team reflected on many visions and scenarios, including previous Mansholt Lectures, to overcome the tremendous challenges we are facing in meeting the land-use demands of our food, non-food, nature and biodiversity requirements in the EU. Climate change, pollution, food and non-food security, overconsumption, exhaustion of natural resources and geographical tensions are key factors influencing (future) land use in the EU. President of the European Commission (EC), Ursula von der Leyen, recently received the final report of the Strategic Dialogue on the Future of EU Agriculture (Strategic Dialogue, 2024). This report offers a shared prospect for farming and food in Europe, including challenges and opportunities. The EC will prioritise fostering ongoing dialogue and mutual trust among diverse viewpoints, highlighted in this report.

With this Mansholt Lecture, WUR would like to show its support for the Strategic EU Dialogue and provide insights for the further elaboration of vision and policy. In 2023, WUR published a report elaborating six dilemmas on the future of agriculture, food and nature, specifically for the Netherlands (Bos et al., 2024a). These dilemmas were by no means an exhaustive list, but considered topics for multi-actor discussion, marking the start of a dialogue between various parties, challenging stakeholders to look at issues from different angles. This Mansholt Lecture might be considered the European follow-up to this national discussion, broadening the dilemmas to the EU level. By formulating five key dilemmas to discuss future land use for agriculture, forestry and nature, we support the need for ongoing dialogue in the EU. A dialogue, which is much required to give direction to a long-term EU perspective for the future of agriculture, forestry and nature.

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President Executive Board of Wageningen University & Research

Summary

The Mansholt Lecture is an annual event held in Brussels, organised by Wageningen University & Research (WUR). Its purpose is to inspire European policymakers and stakeholders on critical societal issues, particularly those related to sustainable agri-food systems and the living environment.

This 2024 Mansholt Lecture focuses on the future use of land in relation to agriculture, forestry and nature. Land is a finite source for which there are competing demands from recreation, and urban and industrial expansion. Land is also the basis for producing plant biomass, needed for food, feed, and non-food applications. With aspirations to increase self-sufficiency for food and non-food products in the European Union (EU), the demand for biomass, and therefore land, will increase.

Current biomass demand for food, feed and non-food is already high. Yet the use of biomass for food and feed is expected to stay at the current level, up until 2040. The need to transition away from the use of fossil fuels, however, will increase the use of biomass for chemicals and materials that are now produced from fossil feedstock. The manoeuvring space to balance supply and demand in biomass lies mostly in the demand for feed, which outstrips demand for any other food or non-food product. Without changes to our lifestyle in the EU, land could become a bottleneck in the supply of biomass.

This understanding led to the formulation of 5 important dilemmas for the EU dialogue, related to the future supply and demand for biomass and its implications for land use. We do not claim these are the only dilemmas. However, choices within the range of these 5 dilemmas will have a major impact on the future use of our land.

The dilemmas are listed (in no order of importance) as follows:

1. To what extent should the EU pursue self-sufficiency in its food and non-food biomass supply?
2. What roles are envisioned for animal husbandry in the EU?
3. Climate and biodiversity targets: a shared EU responsibility or tailored to each Member State?
4. At what scale should food and non-food biomass production coexist with biodiversity and address climate targets?
5. To what extent should policies intervene in consumer behaviour?

Dilemma 1 | To what extent should the EU pursue self-sufficiency in its food and non-food biomass supply?

In terms of availability of food, the EU can be regarded as food secure. However, the self-sufficiency of the EU heavily relies on imported inputs like fertilisers, energy and feed. What does it mean if the EU wants to become more independent in terms of imports of key resources and thus imports of land use. The current degree of self-sufficiency suggests that the EU could produce sufficient food in the EU to feed its population, provided the production of protein crops and oilseeds increases and consumption patterns change. Additionally, the EU could produce sufficient biomass for non-food demand, if the use of biomass for feed and fuel is curbed. The first challenge in such a scenario is to secure inputs such as energy and fertilisers. The second challenge is: what governance is needed to transition to an 'autonomous' EU food/non-food system?

Dilemma 2 | What roles are envisioned for animal husbandry in the EU?

The size of the EU livestock population has a major impact on people, the climate, the environment and biodiversity. There is growing attention for animal welfare and discussion on whether it is morally justified to keep and take the lives of animals for the benefit of humans. Leaving this moral issue aside, if consumption levels in the EU are maintained at current levels, reducing the ecological impact on the climate and biodiversity of animal husbandry, is a challenge. The production of feed ingredients in the EU, and especially elsewhere for the EU livestock industry, will also continue to compete with the production of crops suitable for human consumption. An alternative vision for animal husbandry could focus on utilising raw materials and waste streams, which do not compete with human food consumption as the basis for the sector's scale. The consumption level of animal proteins and the ensuing effects on land use – both inside and outside the EU – is thus key in this dilemma.

Dilemma 3 | Climate and biodiversity targets: a shared EU responsibility or tailored to each Member State?

The European Climate Law has set a target to reduce net greenhouse gas emissions. The effort to achieve this is currently shared between Member States, allowing trading of carbon budgets, as well as banking and borrowing between years, within Member States – at least until 2029. A key question for the EU dialogue is how climate goals could be allocated and/or traded among Member States after 2030? This can highly impact the way land is developed for both agriculture and nature in the EU. For example, the extent of permissible GHG emissions affects the patterns of intensification and de-intensification of livestock. The related issue of nature restoration complicates matters too, as unlike carbon, nature and biodiversity are not perfectly substitutable. On the one hand, nature and biodiversity are not evenly distributed across Member States. Uneven effort sharing could open strategic opportunities to leverage specific geographical, biophysical and socio-economic qualities of a country or area. On the other hand, is a scenario of uneven sharing of restoration responsibility strategic and feasible? If so, what type of governance arrangements would be needed to achieve this?

Dilemma 4 | At what scale should food and non-food biomass production coexist with biodiversity and address climate targets?

There are many options to combine food and resource autonomy, reduce greenhouse gas (GHG) emissions and increase biodiversity. Yet all have impact on land use. On the one hand, more biomass production for food and biobased resources is currently possible, but on the other, in future climates both land availability and productivity are expected to decline. The EU ambitions for biodiversity, GHG emissions and resource autonomy will likely result in competing claims on land. However, what should have priority? Changes in domestic biomass production directly affect the required import of food, feed and resources for the biobased economy, if the demand remains the same. Should the impacts of imported products and domestic production be accounted for, in the same way? Should we prevent the externalisation of impacts of EU land use changes on GHG emissions elsewhere, by better synchronising land use changes and changes in consumption?

Dilemma 5 | To what extent should policies intervene in consumer behaviour?

Current consumer behaviour patterns significantly influence our climate, the environment, biodiversity, and consumers' own health. Focus is often on diets, but non-food consumption patterns, such as clothing, are influential too. A shift to more sustainable consumption patterns is needed. However, public steering in our consumer behaviour, particularly in the realm of nutrition and fashion, is a socially and politically delicate matter. On the one hand, consumers enjoy a degree of choice and there is hesitation to intervene. The freedom to choose one's own purchase is often perceived as a social right and an individual responsibility. On the other hand, there is also societal support for more active government interventions to stimulate healthier and more sustainable consumption patterns. How far should policies guide consumer choices?

Navigating the complexity

There are already a range of possible directions to explore in each of the dilemmas above. Adding a further layer of complexity is that these dilemmas are strongly interconnected – decisions made in one dilemma could limit options in others. Even when examining each dilemma on its own, choices are not unlimited. International agreements, the EU's foundation of an open-border economy, and competing spatial demands within and between Member States, all influence which options appear viable and which do not. However, it is important not to make these decisions in policy siloes.

We will need whole-of-society approaches to decisions across these five dilemmas, as they will shape the future of our food and non-food biobased system, nature and biodiversity outcomes, and overall quality of life. These choices concern the structure of Europe, the international standing of European agriculture and forestry in the global arena, the role and scale of animal husbandry, and the interaction between our biomass supply, demand and nature and biodiversity. Alternative options will need to be inclusively negotiated, both with stakeholders who have power to influence decisions and those who are affected by the decisions. Choices should be made by negotiating what is an environmentally safe boundary (thresholds for environmental sustainability) and a socially just foundation (social inclusion thresholds). This sets a 'Safe and Just Operating Space', within which multiple pathways towards the future can co-exist. Each decision will come with its own set of pros and cons, requiring careful consideration.

Postponing decisions will only further compound the challenges we are facing towards reaching the European goals for sustainable food and non-food systems.
In this domain, knowledge is continually advancing. As insights evolve, WUR remains committed to sharing scientific knowledge to ensure that dialogues are informed by up-to-date research.

The proposed new platform, offered as part of the Commission's Strategic Dialogue on the Future of EU Agriculture, is a promising signal of the Commission's commitment to foster dialogue on these dilemmas (Strategic Dialogue, 2024).

1 Introduction

From a historic retrospective …

The European Union (EU), now consisting of 27 Member States and more than 449 million inhabitants, was established by the Treaty of Maastricht in 1992. It was the follow-up to the European Economic Community (EEC), instituted in 1957 by the Treaty of Rome. The EU is a single market, offering the Member States free internal access for goods, services and production factors. The Union's territory covers a large variety of economic, social and environmental conditions.

The Common Agricultural Policy (CAP) was the first truly integrated policy, with the first common market organisations dating back to 1962. In the early days of the Community, agriculture was certainly seen as an obstacle to European integration due to the very different national ideas of the six founding fathers of the EU on how to shape policy for the sector. Agriculture eventually became a 'frontrunner in the integration process' (Meester and Dries, 2013). In the 1950s, the major aims were food self-sufficiency and food security for all Europeans by modernising food production, increasing agricultural productivity, ensuring a fair standard of living for persons engaged in agriculture, stabilising agricultural markets, assuring the availability of supplies and ensuring reasonable prices for consumers. The impact of agriculture on the quality of air, water and land, climate and nature was not considered an issue. Over the years, the influence of the EU grew to include policies on various joint domains, such as the economic development of regions, external trade, food safety, nature and biodiversity, climate and rural development. Currently the CAP has 10 objectives, including targets concerning climate change, environmental care and protecting landscapes and biodiversity.

… towards current challenges

According to Land use statistics (Eurostat, 2021), the EU has over 411 Mha of land of which roughly 160 Mha is used for agriculture, including permanent crops. Another 160 - 170 Mha is in use as woodland. The area under agriculture varies strongly throughout the EU, ranging from 10% of the area in Scandinavian member states, up to 55-70% of the land area in Western and Central European member states. With an average share of around 38% of the European Union's land coverage, agriculture leaves a large mark on the EU's biophysical environment. This is space that other sectors are also increasingly relying on, leading to the need in parts of the EU for careful considerations on how to use land. In addition, land use is under pressure from changes in climate. Climate zones are shifting, river flows are changing, and crop production is hampered by extreme weather events that occur more frequently, such as severe droughts, and large downpours with floods or hail. Land is the basis for the production of plant biomass, which is used for food, feed, and non-food products such as fibres, materials and fuel, and also soil. Land is also a finite source and given the challenges mentioned, land could become a bottleneck in the supply of biomass for the different purposes.

Research often focuses on finding pathways towards sustainable and resilient solutions. Instead of providing visions or scenarios, this Mansholt Lecture 2024 formulates key dilemmas on the future land use of the EU related to agriculture, forestry and nature, to feed the EU dialogue.

The basis for our dilemmas is the future demand for and the supply of plant biomass. Photosynthesis is required for all life on earth and creates plant biomass, the source of organic carbon needed by humans and animals. Biomass also represents a source of organic matter to maintain soil biodiversity, water infiltration and associated soil production functions, such as soil water retention capacity and nutrient exchange capacity. Since all demand and supply by humans and animals goes via direct and indirect consumption of plant biomass, it is a useful (physical) concept as a common currency, to analyse the match between supply and demand. After analysing plant biomass, a conversion to land use can be made.

Biomass production competes with other land functions and intensification of biomass production directly affects the quality of water and air, leading to human health issues and degradation of nature and biodiversity. In large parts of the EU, biomass production and nature are difficult to combine within landscapes dominated by intensive agriculture and forestry. Spatial planning for biomass production has thus become separated from spatial planning for the protection of nature and biodiversity. In addition, biomass production in the EU is currently dependent on import of nutrients via feed or fertiliser and of energy. Feed imports could be reduced if we grow more feed locally or move to a more plant-based diet and reduce livestock numbers. Imports of energy could be brought down if we would use more renewable energy sources that are not derived from biomass, while fertiliser requirements can be reduced by increasing circularity and re-use of nutrients in the food system. This requires choices to balance short term needs and demands with a long-term vision of a climate-proofed and sustainable EU, in which both people and nature thrive. These choices are neither simple nor one-dimensional, but create dilemmas, as the system is complex, has many interactions, many different stakeholders and many interests. Many actors act from their own perspective, ignoring others, which leads to polarised debates. There is also not one single optimal solution.

Central to all these challenges is our lifestyle and more specifically the fact that we as humans are consuming more resources than the earth can supply sustainably. This is perfectly illustrated by the ever-earlier occurrence of Earth Overshoot Day: the date in the year when humanity's demand on nature's resources surpasses Earth's capacity to regenerate them for the given year (Earth Overshoot Day, 2024). Are we willing and able to change our way of living, in order to save our planet? Can we change food and non-food consumption patterns and adapt our production methods to restore the balance? Changing these patterns implies that important choices have to be made, related to land use as a finite resource and to the production of biomass. Transitioning away from the use of fossil fuels means that an increasing proportion of our raw materials for clothing, interiors, buildings and other items will have to come from biomass. This growing demand from non-food sectors increases the need for agricultural land area and land use intensity, and poses a tremendous challenge within the EU and elsewhere, if we increase our import of biomass. The actual demand depends on consumer behaviour and the choices we make in our daily lives with respect to the food and non-food products we consume.

What to expect from this report?

There is widespread acknowledgement of the need for a more sustainable food and non-food biobased system, to address the issues of climate change and biodiversity loss. However, the many options and extent of the necessary changes is a topic of much debate in the EU. It is against this background, and in light of the international targets to which the EU has committed itself in the areas of climate and biodiversity, that we focus this Mansholt Lecture 2024 on the use of land in the EU for biomass production and the choices that are possible therein. This report aspires to feed the required political and social dialogue within the context of future land use, by providing scientific insights and alternative perspectives. Therefore, we need to consider the issues and developments we are facing today from a broader and longer-term outlook, taking into account key challenges regarding the long-term security of our essential resources, including clean water, clean air, healthy biodiverse landscapes with sufficient food, nutrition and materials. We should acknowledge the need to act within the constraints defined by the need to protect the quality of water and air, to reduce GHG emissions, to adapt to climate change and to restore biodiversity.

Chapter 2 explains the challenges concerning the production of biomass and the consumption of the derived food and non-food products in the EU, and the consequent land use implications. In Chapters 3 to 8 we present five dilemmas for the dialogue across the EU, without being exhaustive. We also explore some of the consequences of choices within the margins of these dilemmas. We hope that by discussing the dilemmas and showing the complexity, we will contribute to a constructive dialogue about the future of land use in the EU. One which will help us shift away from the polarisation, which is currently hampering the way forward. In Chapter 9, we end with a guiding perspective on how to navigate this complexity.

In our analysis, we restricted ourselves to the use of land-derived biomass in the EU. We are very well aware that this use will play out differently across and within the different Member States and across Europe, which is indeed part of the dialogue. We also realise that in focusing on land-derived biomass, we are excluding a potential source: our marine system. However, it would require a separate study to do justice to this domain.

② Land as limited resource for the demand and supply of food and non-food biomass

2.1 Introduction

There are competing demands for land, since it is not an infinite source. Land is needed for food and non-food production, for nature restoration, and also for recreation, urban and industrial expansion and climate adaptation. The demand for land is increasing, driven largely by the increasing consumption of biomass products. With aspirations to increase the EU self-sufficiency for food and non-food products, this demand will further increase.

In this chapter we discuss the magnitude of the current demand and supply using the concept of biomass. Biomass is a useful concept because it represents a 'common currency' for measuring the extent of:

- food for human consumption;
- feed for animal consumption;
- non-food, which can be separated in:
  - fibrous materials, such as textiles, construction materials such as wood and paper/board;
  - fuel for transport purposes, replacing fossil fuels, gasoline and diesel;
  - fuel for energy/electricity production replacing fossil fuels;
  - organic chemicals and their products such as plastics, rubbers, textiles, fine chemicals, replacing fossil-based chemicals;
- soil (quality) – here, biomass represents a source of organic matter to maintain soil production functions as water and nutrient holding capacity, soil biodiversity.

2.2 Demand for biomass in the EU

Figure 2.1 provides an overview of the present and projected future demand (year 2050) for biomass in the EU. It shows that the use of biomass for feed is by far the highest, now and in the future. Demand for feed surpasses the expected demand for any other food or non-food product by far. Figure 2.1 also shows that use of biomass for food and feed is expected to stay at the current level, due to a non-growing population and assuming dietary changes for both humans and animals will not occur. For non-food demand the situation is quite the opposite. This demand will grow by a factor 5 to 10. In total, demand for plant biomass is expected to grow by 20-45% in 2050. Current total annual demand for plant biomass in the food and non-food domain in the EU is 782 Mt/y of dry matter, excluding woody biomass. Future demand is expected to increase to somewhere between 915 and 1115 Mt/y of biomass, excluding woody biomass, which is expected to grow by a maximum of 30%. From Figure 2.1 it becomes apparent that potential room for manoeuvre to meet future biomass demand, is mostly found in feed production. Additionally, implementation of more circular approaches can help to reduce demand for biomass.

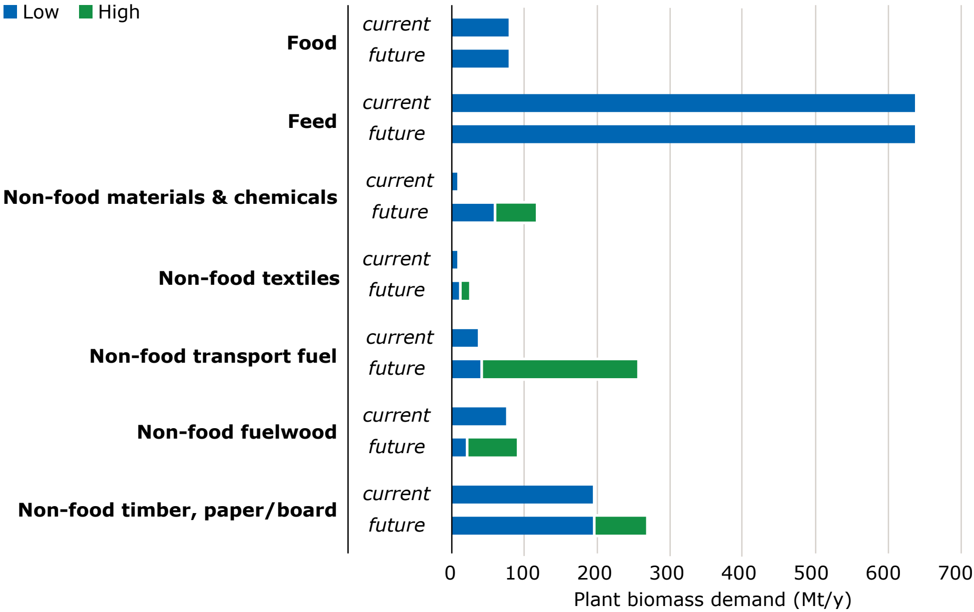

Figure 2.1 Current and future demand for plant biomass products in the EU (in Mt/y). Details about calculations and technical backgrounds are described in Appendix A. Source: own calculations.

The increase in biomass demand from the replacement of fossil fuels, is largely restricted to the higher-end applications (e.g. bioplastics), as there is wide acknowledgement in the EU that using biomass for all electricity, heat and transport applications is not realistic. The biomass used for energy and transport is thus regarded as a temporary demand until alternative technologies have reached scale. The energy transition is taking up speed which leads to the introduction of a variety of new and innovative renewable energy technologies. The energy transition focuses on decarbonisation, away from the use of carbon-based energy carriers, by using sun, water and wind instead. However, phasing out fossil fuels poses a problem for the chemicals and materials that are presently produced from fossil oil and gas, since the carbon atom is their main constituent. Biobased materials are also based on carbon and therefore, biobased and fossil-based materials are often referred to as carbon-based materials. The area of non-food applications of biomass is expected to be the most dynamic in the coming decades, as it has already been in the last two decades by the increase of biomass for transport fuel and power plants.

The importance of carbon-based materials (fossil and bio-based together) in our everyday life may be difficult to grasp, but is nicely illustrated in Figure 2.2. The right hand drawing shows what the living room on the left hand side would look like, without any carbon-based materials.

Figure 2.2 Our life with (left) and without (right) carbon-based materials, from fossil & biomass resources.

Basically, there are two different groups of relevant applications where demand is expected to change: non-food crops that provide fibre and wood (textiles, paper and board, timber, building materials, etc.), and crops that provide feedstock for chemicals and materials (bioplastics and other replacements of fossil-based materials and chemicals). The growth in non-food fibrous crops for textiles is expected to be significant, when fossil polyester is to be phased out, while the demand for paper and wood for timber will show a moderate increase. The most important development is the increased feedstock demand for chemicals and materials.

A flavour of the relative demand of all carbon-based materials (fossil and biomass together) in the different application categories, can be derived from Figure 2.3. This shows the worldwide market demand for these materials is grouped. The relative numbers in material use in the EU are expected to show a similar distribution, compared to these global data (Bos et al., 2024b). Biomass is already important as a resource for paper and board, timber and textiles. Additional non-food demand comes mainly from plastics and the fossil share of textiles.

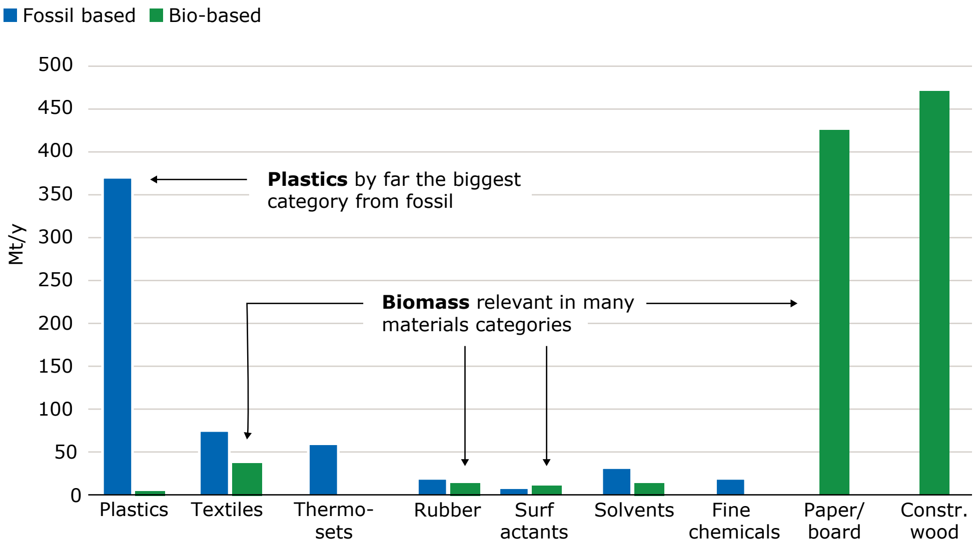

Figure 2.3 World-wide market demand for all carbon-based materials, fossil and biomass combined. Source: adapted from Bos et al. (2024b).

The demand for biomass for soil is hard to quantify. However, it requires attention because biomass represents the carbon for soils, which is essential to maintain ecosystem services such as nutrient and water cycles, and carbon sequestration. The latter contributes to climate change mitigation. The increasing demand for biomass should not be at the expense of biomass supplied by roots, stubbles and crop residues, needed to replenish soil organic matter that is mineralised.

2.3 Production of biomass in the EU

The annual agricultural biomass production in the EU is almost 700 Mt/y of dry matter, of which the vast majority is grass, feed and fodder, followed by cereals (Figure 2.4). Non-food biomass in the form of roundwood production is approximately 270 Mt/y of roundwood (Camia et al., 2018). Currently, almost 25% of the roundwood production is used as fuelwood.

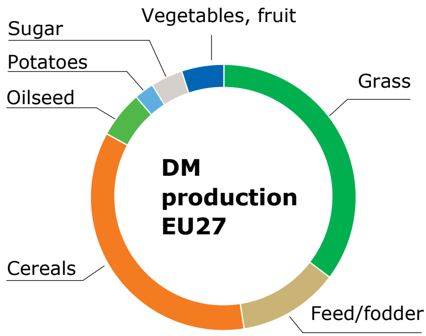

Figure 2.4 The shares of the major crop groups in total agricultural biomass production on dry matter (DM) basis in 2022. Source: Eurostat, 2024a.

Import and export

The EU compensates for production gaps and surpluses in biomass through trade. In 2023, a total of 71 Mt/y of biomass for feed was imported (EU feed protein balance sheet: European Commission, 2024a), 47 Mt/y of cereals and other products were exported. The net physical import and export trading is therefore relatively small. In the last decade, the EU shifted from being a net importer of roundwood, to a net exporter of 12 Mm^3 in 2022 (Eurostat, 2024a), which is 2% compared to the European roundwood production of 510 Mm^3.

Future crop production

Plant biomass production in the EU will be affected by a range of factors:

- current agricultural practices are to some extent unsustainable, the use of pesticides and chemical fertilisers needs to be reduced to protect biodiversity and public health (Eurostat, 2024b; European Environment Agency, 2023a);
  - reducing the use of inputs and pesticides may lead to lower production;
- a large area of the EU is under threat from increased aridity, while about 25% of land used for agriculture is currently at risk of desertification (European Court of Auditors, 2018);
- land abandonment is a matter of serious concern, with the risk of loosing 5 million hectares by 2030 (Schuh et al, 2020), which might increase in the years after;
- the yield gap analysis shows a potential increase of production by 20-25%, mostly in the eastern member states;

- however, further intensification of production will be needed to improve current biomass yields and this might have impact on biodiversity, the environment and natural areas.

Appendix A contains a more detailed elaboration of these factors. Although it is hard to quantify future production, the mentioned factors indicate that a decrease in plant biomass production is more likely to occur than an increase. An increase might still be possible in some regions, while in other regions a net decrease in production could be substantial.

2.4 The relation between food, feed, fuel, fibre and non-food

Food and non-food products often require the same crops and are interconnected. Protein rich and partly fibrous co-products are often produced during the production of food, or transport fuels and are usually used as feed for livestock.

It is often stated that non-food applications, in particular chemicals and bioplastics, need to be produced from agricultural side-streams or co-products, which are not fit for human consumption. It is however questionable whether this is the best route, as these non-food applications require typically non-fibrous carbohydrates instead of proteins and fibrous products as resource. Many processes for chemicals and materials also preferably use relatively clean input streams. While there has been attention to developing second-generation technologies to make lignocellulosic side streams available for the production of chemicals, these have not yet been implemented at large scale. At the same time, non-food crops for fibre and wood are stand-alone crops, and not merely side-streams. An integrated food and non-food production system, with more circular farming systems and an optional shift towards more plant-based proteins, could make additional room for the production of crops for non-food applications. This refers to both timber and fibre, as well as resources for the chemical industry. The production of high value polymers, plastics and chemicals could, for instance, be based on the carbohydrates that become available during the production of plant-based proteins from cereals. Fibrous side-streams of this integrated production system for food and non-food can become available as feed for the animal production system. This approach extends the circularity principle from food production to combined food and non-food production.

2.5 Circularity as a means to reduce the demand for new biomass

Improving circularity in products is often assessed along the lines of the R strategies (Table 2.1). The most efficient and effective strategies to diminish the use of resources, lie in the lower R numbers: smarter product use and manufacturing and extending the lifespan of a product and its parts. Recycling is only one of the final options to improve circularity and it can only be done effectively if future recycling options are considered in the design phase.

Table 2.1 The 9R framework: strategy and explanation.

Strategy		Explanation	
Smarter product use and manufacture	**R0**	*Refuse*	Make the product redundant by abandoning its function or by offering the same function with a radically different product
	R1	*Rethink*	Make the product use more intensive (e.g., through sharing products, or by putting multi-functional products on the market)
	R2	*Reduce*	Increase efficiency in product manufacture or use by consuming fewer natural resources and materials
Extend lifespan of product and its parts	**R3**	*Re-use*	Re-use by another consumer of discarded product which is still in good condition and fulfils its original function
	R4	*Repair*	Repair and maintenance of defective product so it can be used with its original function
	R5	*Refurbish*	Restore an old product and bring it up to date
	R6	*Remanu-facture*	Use parts of discarded product in a new product with the same function
	R7	*Repurpose*	Use discarded product or its parts in a new product with a different function
Useful application of materials	**R8**	*Recycle*	Process materials to obtain the same (high grade) or lower (low grade) quality
	R9	*Recover*	Incineration of materials with energy recovery

Source: Potting et al., 2017.

For textiles, plastics, building materials and other products, these strategies can be applied directly. However, only a few of these strategies can be applied for food:

- **R0 - *Refuse*** can be applied for animal proteins;
- **R1 - *Rethink*** can be applied for consuming less ultra-processed[1] food;
- **R2 - *Reduce*** can be applied for using biomass feedstock for multiple applications;
- **R9 - *Recover*** can be applied for recovering nutrients from human excreta.

The lower number R-strategies can be expected to have more impact on lowering feedstock demand and thus land use. For biomass-based products, these strategies might need to be rephrased. Table 2.2 captures options within the 9R Framework.

1 There has been a trend of moving more and more towards the consumption of packaged and ultra-processed food with low nutrient value. Source: https://op.europa.eu/en/publication-detail/-/publication/86e31158-2563-11eb-9d7e-01aa75ed71a1

Table 2.2 The 9R Framework: options adapted for plant biomass.

	R-options		
Food	***R2***	*Reduce*	Reduce food waste
	R8	*Recycle*	Recycle nutrients (N, P, K, etc.)
Feed	***R0***	*Refuse*	Less meat/milk/eggs
	R2	*Reduce*	Reduce food waste
Fuel	***R0***	*Refuse*	Shift to production via non-biomass way, decarbonisation
	R2	*Reduce*	Use less energy
Fibre/timber	***R0-R2***	*Refuse - Reduce*	Refrain from fast fashion, fast furniture
	R3-R7	*Extend lifespan*	Repair, etc.
	R8	*Recycle*	Recycle
Chemicals/ plastics	***R0-R2***	*Refuse - Reduce*	Refrain from fast fashion, limit plastics use
	R3-R7	*Extend lifespan*	Repair, etc.
	R8	*Recycle*	Recycle

Source: Potting et al., 2017.

2.6 Many choices about multiple land use demands

The combined estimate of land use, related to the expected development in plant biomass demand (from section 2.2), and the development in land use and productivity in the EU (section 2.3), is illustrated in Figure 2.5. Detailed calculations can be found in Appendix A. The current land use balance shows a limited net use of land outside the EU, which is the result of the physical trade balance between the large import of feed (mainly oilseeds, oilseed cakes and maize) and the large export of cereals and other products. This is estimated at about 30 million hectares, which is in the range as analysed by O'Brien et al. (2015). In a scenario with low plant biomass demand and limited loss of agricultural land in the EU, this physical trade balance will increase up to 60 million hectares. At the other extreme, in a scenario of high demand with high agricultural land loss and land productivity remaining the same, the physical trade balance increases up to 200 million hectares of land use outside the EU.

This has large implications for EU self-sufficiency, with the high demand scenario representing a large increase in dependency on plant biomass. Using more land outside the EU will lead to stronger competition with other regions, as it can be expected that their demand for biomass and land productivity will show similar trends. It is also noteworthy that part of the EU trade footprint has very large implications for tropical deforestation and global biodiversity loss.

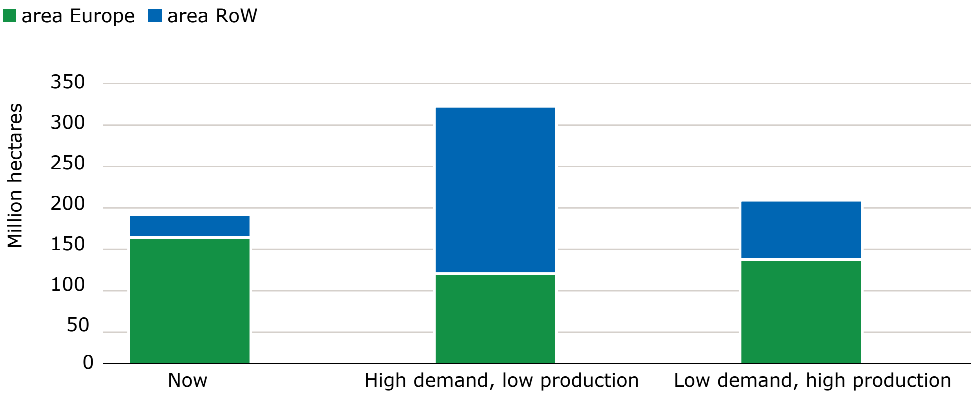

Figure 2.5 The estimated land use in the EU and the required land use in the Rest of the World (RoW) to meet EU plant-based biomass demand in the current situation and in the future, by 2050. Detailed information is described in Appendix A. Source: own calculations.

Managing this competition requires managing both demand and supply. There are many choices to be made on how to use land in the EU. Do we reduce consumption, shift to diets with more plant-based proteins and increase circularity? What do each of these strategies mean for nature, climate and different sectors and stakeholders? Drawing on recent scholarly literature and the practical experience of interdisciplinary scientists from agriculture, ecology, biobased technologies, economics, social and political sciences, we distil five key dilemmas that need to be openly discussed to come to environmentally safe and equitable decisions. These are certainly not the only dilemmas, but potentially some of the most pressing ones for EU policy makers to consider.

③ Five dilemmas for the EU dialogue

Based on the previous chapter (2), we derived 5 important dilemmas for the EU dialogue. These are related to future biomass supply and demand and its implications for land use, based on several WUR land use studies, visions and scenarios. We do not claim that these are the only dilemmas. However, choices within the range of these 5 dilemmas will have a major impact on the future use of our land. We therefore recommend that these choices on food and non-food biomass, and their land use implications, are discussed in open EU dialogue.

We acknowledge that dilemmas are not about right or wrong answers. The choice for one option over others, is value-driven. By formulating and explaining these five dilemmas, we aim to provoke evidence-based arguments for debate by multiple actors.

Figure 3.1 A network of five dilemmas.

The five dilemmas are listed (in no order of importance) as follows:

1. To what extent should the EU pursue self-sufficiency in its food and non-food biomass supply?
2. What roles are envisioned for animal husbandry in the EU?
3. Climate and biodiversity targets: a shared EU responsibility or tailored to each Member State?
4. At what scale should food and non-food biomass production coexist with biodiversity and address climate targets?
5. To what extent should policies intervene in consumer behaviour?

The reasoning behind and the importance of these five dilemmas, including the respective questions for the EU dialogue, are explained in the following chapters (4-8). By elaborating the dilemmas, we also highlight the interrelations between the dilemmas in Section 9. This elaboration, in part, draws on the report 'WUR perspectives on agriculture, food and nature in the Netherlands' (Bos et al., 2024a).

④ Dilemma 1 | To what extent should the EU pursue self-sufficiency in its food and non-food biomass supply?

4.1 Introduction

Food availability is not the issue …

In terms of availability of food, the EU can be regarded as food secure. The EU is to a certain extent self-sufficient for many products, with the exception of a number of protein crops and oilseeds, as well as tropical products like coffee, tea and fruits. However, the self-sufficiency of the EU heavily relies on imported inputs like fertilisers, energy and feed (Loi et al., 2024). At sector level (agriculture, fisheries and aquaculture, food and beverages) the dependency ratio, defined as the ratio between the value of imported input and the total input value, varies between 7 and 11%. This is not very high, indicating that at this general level, the EU food system is resilient. However, for selected inputs, the dependency can be as high as 31% (potash), 68% (phosphates) or 84% (soya beans). The dependency on imported products is especially significant for animal products. In addition, there is a strong geographical concentration for the import of a series of products (Loi et al., 2024). For feed, South and North America are main players, for mined fertiliser resources (e.g. phosphorus and potassium), Morocco, Russia and Belarus are important players. Loi et al. (2024) also mention the dependency on natural gas and other energy sources for the production of nitrogen fertilisers. For energy, the imports-depedency rate, defined as the share of net imports (imports minus exports) in gross inland energy consumption in the EU in 2022, was 63% (Eurostat, 2024c). In the unlikely event that all external EU-trade would come to a grinding halt, food production in the EU is most likely to be affected by a shortage of energy and fertilisers.

… food security is about affordability

Food security is defined by the Food and Agricultural Organisation (FAO) of the United Nations, as the situation where people at all times have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life (FAO, 2009). It is about the availability of and, crucially, access to food supply. A great deal of food insecurity is a consequence of lack of access and poor nutrition, not because of a food shortage.

This definition of food security is not fixed and has changed over the past 50 years, from one of availability to other issues. Currently, there is debate as to the inclusion of agency and sustainability in the definition (Clapp et al., 2022). Agency refers to the capacity of individuals and groups to exercise a degree of control over their own circumstances and to provide meaningful input into governance processes. Sustainability refers to 'food system practices' that contribute to long-term regeneration of natural, social, and economic systems, ensuring the food needs of the present generations are met without compromising food needs of future generations (Clapp et al., 2022).

Access to food is not a given for every inhabitant in the EU. In 2022, one out of 12 persons in the EU (8.3% of the EU population) could not afford a meal containing meat, fish or a vegetarian equivalent every second day. This is an increase compared to 2021 (one out of 14 or 7.3%). The number of people considered at risk of poverty also grew, from 17.5% in 2021 to 19.7% in 2022. There is a large variety between Member States, with the highest shares recorded in Bulgaria and Romania and the lowest in Ireland and Luxembourg in 2023 (Eurostat, 2023c). These figures show the social dimension of food security within the EU: despite the fact that sufficient food is produced in the EU to feed every inhabitant, not everyone enjoys the same level of food security, due to a lack of means.

Non-food applications of biomass are expected to grow

In terms of the production of non-food (carbon based) materials, the EU relies heavily on import of textiles. Furthermore, the EU has a large (petro) chemical industry, of which the main feedstock is (imported) fossil oil. Diversifying the chemical industry towards the use of biobased resources, thus implies that Europe may become more self-sufficient for chemicals. At the same time, this also requires structural changes in the chemical infrastructure, as some conversion processes will be totally different when based on biobased feedstock.

EU imports of bioethanol for fuel increased significantly in recent years (EUR-Lex, 2023). Biodiesel is produced in the EU, and recently the EU imposed anti-dumping tariffs on biodiesel imports to support EU biodiesel production (Biofuels International, 2024). Furthermore, especially for transport fuels, the EU is transitioning towards electrification, hydrogen and other energy solutions, that may be more easily generated or produced within the EU.

The EU imports wood from a range of countries and exports a limited amount of wood. The new EU forest strategy (European Commission, 2023a) focuses on the restoration of forests for carbon storage and sequestration, reduction of the effects of air pollution on human health and halting loss of habitats and species. The strategy also aims to guarantee the availability of wood and boost non-wood forest-based economic activities to diversify local economies and jobs in rural areas.

Undoubtedly, these additional demands for biomass will put further pressure on land use. The other side of the coin is that there is only a limited area of suitable land for agricultural purposes in the EU. This area is under pressure with nature, housing, infrastructure and energy production all making claims on it. The additional demand of biomass therefore needs to be considered in the context of the demand for food and materials, and especially feed and energy/transport fuels.

4.2 The importance of dilemma 1

There are a number of reasons why the EU should consider its position as it plans for the future. On the one hand, agriculture in the EU is facing a variety of significant sustainability challenges, such as climate change mitigation and adaptation, biodiversity restoration, and water scarcity that may impact the available land for agricultural production and the land productivity.

At the same time, the impacts of climate change are likely to lead to an increase, rather than a decrease, in the relative and strategic importance of different areas in the EU, due to their changing suitability for agricultural production. While the effects of climate change are being felt in temperate zones such as north-west Europe, it is in southern Europe (along with other parts of the world) that food production is already strongly affected by worsening water shortages and higher temperatures (European Environment Agency, 2023b).

The EU is also already dependent on land use outside EU. According to a Joint

Research Centre (JRC) study (2024a) the EU imported a cropland of 50 million hectares (ha) – roughly the size of Spain – and exported a cropland equivalent to 28 million ha (about half of the imports) in 2021. Argentina, Brazil and Ukraine were the top three 'cropland' exporting countries to the EU. The main goods were vegetable oils (e.g. palm oil and sunflower seed oil), oil seed crops (e.g. rapeseed and soybeans), and residues of food industries, such as oilcakes (mostly to be used as animal feed) (ibidem).

Finally, as illustrated by the outbreak of COVID-19 and the war in Ukraine, supply of food and of necessary inputs can easily be disrupted, and followed by price spikes. Wheat prices went up sharply after the Russian invasion in Ukraine in 2022, as well as prices of other food products – although there was no actual food shortage. Food prices had already been on the rise for a longer period due to a combination of factors e.g. COVID disruptions to trade, economic recovery from the pandemic in 2021, and product-specific causes, including droughts and the large-scale outbreak of African swine fever in China. Sharply increasing energy costs since the second half of 2021, also played an important role (Berkhout et al., 2022).

While often underexposed when discussing the use of biomass, the EU's dependency on other countries for materials and products is also vulnerable. In the EU list of critical raw materials (EUR-Lex, 2020), natural rubber is listed. The EU also relies heavily on import of textiles. In the EU strategy for sustainable and circular textiles, self-sufficiency or production of textile fibres within the EU are not addressed. In this case, the EU tries to influence the international production chain by setting standards strongly aimed at reducing the environmental impact of textile products. The EU's share in the world-wide chemicals and traditional plastics production is declining. On the other hand, China, followed by Europe, is the global leader in relation to bio-based plastics production and recycling. Two areas where a larger share of self-sufficiency might be possible and desirable (Plastics Europe, 2023).

4.3 Questions for the EU dialogue

Traditionally, the EU is an open economy that has been able to prosper through international trade. This position has led to dependencies on third countries, which can lead to risks, as recent years have shown. And while food supplies have not been at risk, increased food prices due to geo-political developments have fuelled the debate about what is called *strategic autonomy*.

Strategic autonomy is not unambiguously defined and EU Member States have different views on what strategic autonomy entails. However, positions are converging towards an explanation of 'the ability to act, together with partners when possible, alone when needed' (Zandee et al., 2020). Initially, strategic autonomy was mainly about security and defence[2], but over time the term has taken on a broader meaning. The COVID-19 pandemic pointed out the need to think about the foreign supply chain dependencies in the food sector. The war in Ukraine further sparked the discussion (European Parliament, 2022).

What does it mean if the EU wants to become more independent in terms of imported land use and imports of key resources? We might suppose that the EU should be completely self-sufficient for food/non-food and the necessary inputs. This is an extreme assumption, which can be useful if we want to think about the EU's most vulnerable spots in the food system and about options for action. What would this mean for dietary variety? For food affordability? What would be the consequences in terms of land use *within* the EU? What shifts in production would be necessary to provide every EU citizen with enough food? What changes would be needed in terms of energy-production and use? In terms of fertiliser use, and the associated energy needed for its production? How much do we want the EU chemical industry to rely on agricultural production for their inputs?

The current degree of self-sufficiency suggests that the EU could produce enough food in the EU to feed its population, provided the production of protein crops and oilseeds is increased, and consumption patterns change towards less intake of animal proteins (Joint Research Centre, 2024b). Additionally, the EU could produce enough carbon-based materials provided production of feed and fuel is curbed. The first challenge in such a scenario is to secure inputs like energy and fertilisers. The second challenge is: what is the governance needed to transition to an 'autonomous' EU-food/non-food system? How much government intervention would be necessary? Or could this be left to the market? How could the Common Agricultural Policy be put to use in such a scenario? For instance, should the production of oilseeds and proteins in the EU be incentivised?

2 According to the European Parliament (2022), the first official EU document containing the expression 'strategic autonomy' appears to be the European Council conclusions on EU common security and defence policy (CSDP) of December 2013.

Supposing a business-as-usual scenario, where everything in terms of the EU dependency on imports stays more or less the same, leads to other questions, equally relevant to think through. What would this mean in terms of land use outside the EU? What effects might there be on third countries? Would the EU merely be passing on problems to other countries, with production needing to be based in those places and generating the associated impacts on the environment and local surroundings in these countries? Could there be higher risks of disruptions in supply, leading to food price increases? What governance arrangements could be put in place, so that nutritionally important food remains affordable for the most vulnerable groups in society? Would a Common Food Policy be helpful in that respect? What would the continuous shifting of externalities to distant countries mean to global issues such as climate change and biodiversity loss? And how would these global crises eventually impact the EU in the long term?

Of course, the opposites are both extremes and not very likely to materialise a full 100%. They do though show the need to think more broadly about a European agricultural land use strategy. This centres on the question of how Europe could become more self-sufficient in the face of global geopolitical instability for food, and the necessary inputs for food production. This question raises a number of complicated tensions: on balance, the amount of available agricultural land is decreasing, partly due to climate change, nature development and urbanisation, while at the same time agricultural productivity is also decreasing due to climate change. However, this does not apply everywhere. In addition, agriculture relies quite heavily on a number of inputs that will not necessarily continue to be available and affordable within its territories:

- fossil energy, which is currently also crucial for nitrogen fertiliser production;
- phosphorus and potassium fertilisers, for which Europe currently relies heavily on other countries such as Belarus and Morocco;
- water;
- labour.

The question then is, how to use the land in the EU wisely so the dependency on imports could be reduced? It will require assessing what functions fit best where, with land use opportunities and constraints ultimately being steered by the biophysical characteristics of the region, to maintain both soil quality, and water quality and availability. It also requires us to make some important choices, including about whether to keep agricultural land available for agriculture, whether to prioritise food over ornamental plant cultivation or raw materials for feed of fuel, and whether to choose sustainable intensification or extensification. It is also about how to make a greater share of the necessary inputs available to increase the resilience of the European food/non-food system, for instance through better application of recycling principles like the re-use of human manure. And last but not least, this issue is very much linked to the consumption pattern of the average EU citizen. The ensuing question is, are we willing to steer consumption behaviour to decrease the demand for biomass? This point is further elaborated in chapter 8 (Dilemma 5).

5 Dilemma 2 | What roles are envisioned for animal husbandry in the EU?

5.1 Introduction

The traditional farm was mostly a mixed farm. Cattle and sheep grazed on land that was not suited, or poorly suited, for arable crop production for arable crop production. Thus, the cattle provided manure for the arable land, ensuring food production and depleting common pastures (see e.g. Slicher van Bath, 1962). Pigs and chickens lived on residuals from the land and household. In recent decades, due to the increased specialisation of farms, the mixed farm has become increasingly segregated. Arable and livestock farming have become separated and farms have grown in size.

Raising pigs and chickens, so-called monogastric animals, has developed rapidly towards more or less footloose systems. This became possible because of the import of significant amounts of soy from South America and elsewhere. Industrial (monogastric) livestock systems tend to concentrate in areas nearby deltas, leading to an accumulation of nutrients and emissions and to problems with odour. There are also concerns about the spread of animal diseases and antibiotic resistance. High livestock densities increase the public health risk of zoonoses, emissions of particulate matter and ammonia and their potential to disease outbreaks, as is currently seen with avian influenza in poultry and wild birds.

Grazing cattle are still largely kept more extensively in the EU. Grazing cattle have an important role in shaping and maintaining the landscape in large parts of the EU, such as in mountain areas and peat moors, utilising plant biomass without any alternative use. However, industrialisation is taking place for ruminants as well, especially in dairy systems. The supply of concentrate feed means that the land of the farm no longer determines the size of the herd, and intensification of production is taking place. The lower costs of production in these intensive systems are putting pressure on the more extensive systems, for which it is becoming increasingly difficult to survive solely on income from agriculture. Pastoral landscapes tend to be abandoned, leaving production potential unutilised, changing landscapes and biodiversity at the same time, ruminants and dairy farming in particular, form a major source of biogenic methane, a greenhouse gas that warms 27 times more than CO_2 (IPCC, 2024). However, ruminants are very important for the management of grassland which, if managed properly, can actually also make a positive contribution to climate goals, biodiversity, landscape maintenance and provide other ecosystem services (e.g. Ripoll-Bosch et al., 2013; Louis Bolk Institute, 2023, in: Bos et al., 2024a, p. 24).

5.2 The importance of dilemma 2

In 2023, there were 1,450 million chicken, 134 million pigs, 75 million bovine cattle, 59 million sheep and 11 million goats in the EU (Eurostat, 2024a). The size of the livestock population has a major impact on people, the climate, the environment and biodiversity. There is growing attention for animal welfare and discussion on whether it is morally justified to keep and take the lives of animals for the benefit of humans. In his book Animal Liberation (1975, in: Bos et al., 2024a, p. 26), Peter Singer argues that there is no justification for treating humans differently from other animals when it comes to their right to happiness. This foundational work supports the notion that animals possess rights as well, which should be integrated into our legal system. On the other hand, livestock played and still plays an important role in human nutrition and livelihood, especially in developing countries (FAO, 2009) and a more traditional view still exists that animals are in service of humankind.

Leaving the moral aspect aside, we focus this dilemma on the function of animal husbandry within the EU. Do we continue to use our animal husbandry sector primarily to respond to the European demand for high-quality animal proteins and use high-quality feed for this purpose, when it could be more efficient for some of that feed to be consumed directly by humans? Or do we choose to feed animals solely with available raw materials that people either cannot or do not want to eat, such as grass, waste streams and by-products? The answer to that question will partly determine the size of the livestock population.

According to the OECD-FAO Outlook 2021- 2030 (OECD-FAO, 2021), growth in global consumption of meat proteins is projected to increase by 14% towards 2030 compared to the base period average of 2018-2020. This growth is driven largely by income and population growth. However, the per capita meat consumption is expected to level off in high income countries.

Currently, consumption per capita of animal protein in the EU is on average 82 grams per capita per day. Animal protein is about 60% of protein supply, plant protein 40% (Simon et al., 2024). The average needed intake of protein, according to the European Food Safety Authority, is 46 grams a day, indicating an overconsumption of 36 grams a day. This implies that reducing protein intake is very well possible. (ibidem).

Traditionally, animals were fed crops and food scraps that people did not use. Today, global livestock farming competes heavily for agricultural land and water to grow feed ingredients like soy, maize, and grain to meet rising animal protein demand. Currently, 75-80% of available agricultural land is dedicated to producing animal feed. Of this, approximately 45% is arable land that could be used for direct food production for humans or for non-food production. Additionally, growing fodder for livestock significantly contributes to land use changes, including deforestation (Our World in Data, 2019b, in: Bos et al., 2024a, p. 24). Land use for producing animal protein is in the range of 40 - 70 m^2 per kg of protein for pork, chicken, milk and eggs and around 150 m2 for beef (De Vries & De Boer, 2010). The production of 1 kg plant protein from wheat requires 15 - 20 m^2 (calculation based on Eurostat).

Current demand for biomass as feed is estimated at 600 to 827 Mt/y (calculated and cited from FEFAC, 2021, 2024 and the EU feed balance: European Commission, 2024a). This is about 5 to 8 times higher than the human plant-based food requirements (see also section 2.2). Also, feed will remain the largest plant biomass demand in the future. About 250 Mt/y of this feed requirement comes from grasslands, where in many cases no alternative crop can be produced. Co-products from the industry are currently about 55 Mt/y, two-thirds of it being oilseed cakes.

5.3 Questions for the EU dialogue

The level of consumption of animal proteins is key in this dilemma. If consumption levels in the EU are maintained at current levels, reducing the ecological impact on the climate and biodiversity is a challenge. Without reducing the livestock population, this would require major adaptations to technology and feed systems, including feed additives and new housing systems and forms of manure processing (for example). In practice, the impact of many of these innovations is often disappointing. These husbandry systems are also more difficult to reconcile with the idea of animal dignity. The production of feed ingredients in the EU, and especially elsewhere, for the EU livestock industry will also continue to compete with the production of crops suitable for human consumption. In this scenario, we must also consider that future competition for biomass production for non-food application will likely increase. Such competition could further restrict the availability of resources for fodder (see section 2.2).

An alternative vision for animal husbandry, copied from Bos et al. (2024a), could focus on utilising grasslands, raw materials and waste streams that do not compete with human food consumption as the basis for the sector's scale. In addition to grasslands, break crops and co-products, this could encompass waste from the food industry and retail, such as products that have passed their sell-by dates. In this more circular approach, the primary role of animals would be to convert these non-human food streams, with the number of animals in a region determined by the availability of these resources, rather than global demand for animal products (De Boer & Van Ittersum, 2018; Van Zanten, 2016; Van Hal, 2019). In such a system, animal husbandry could contribute a meaningful but reduced portion (9-23 grams per person) of our daily protein needs (Van Zanten et al., 2018). In this regard, a distinction has to be made between ruminants, being able to utilise grasslands and fibrous break crops, and monogastrics that can only use low fibrous co-products.

This approach would require significantly less agricultural land for feed production, allowing land to be repurposed for human food, non-food or other non-agricultural uses. Implementing this globally, would necessitate a reduction in the current daily intake of animal proteins in high-income countries (about 50 grams per person, based on Simon et al., 2024). This would enable low-income countries to meet their protein needs. A partial shift towards plant-based proteins in high-income countries, could help to achieve this. It is important to note that even in a system focused entirely on human food production, considerable amounts of feed ingredients would still be generated.

The key question is: what roles are envisioned for animal husbandry in the EU? Reducing the feed demand by reducing the size of the livestock sector will create room for biomass production for other purposes to meet e.g. the growing demand in the non-food domain. It also might create room for more extensive low-input systems, create room for biodiversity and reduce dependency of feed imports from outside the EU. However, such a choice is not without consequences. Does this imply that human consumption should shift towards more plant-based diets? Then who should take on the responsibility to bring about the changes in consumption patterns? What is the role of governments, also looking from a public health perspective and what should be the role of supply chains? What about the right to choose freely what we consume? Would it be acceptable that meat potentially becomes unaffordable or a once-a-week luxury for large groups in society? Or do we want to maintain our diet preferences, leading to increased imports of livestock products? Besides the questions on consumer behaviour (see also Dilemma 5), how will a reduction of livestock affect socio-economic structures and land use in a number of European regions? The other option of maintaining the size of the livestock sector, will likely lead to less drastic changes in land use and socio-economic development of rural areas on the short term. However, this will not be without consequences either. The dependence on imports of plant biomass will increase and environmental, climate and biodiversity goals will become more challenging, as internal pressure to intensify land use will remain.

If we are able to steer livestock production to a reduced volume, what to do next? Are we willing and able to steer livestock production in the direction of an optimal utilisation of plant biomass? Are we able to put ruminants in their role of utilisers of grasslands and producers of other ecosystem and landscape functions? Are we able to stimulate ruminant systems in remote and abandoned regions? And what will be the role and volume of the monogastric sector?

As a potential consequence of reduced livestock numbers and thus feed imports, there may be a need to utilise human manure as a nutrient source to replenish those exported from the farm via plant biomass and animal products. Currently, the largest loss of nutrients in the agricultural food/non-food system is found in 'the smallest chamber' of the consumer’s house.

6 Dilemma 3 | Climate and biodiversity targets: a shared EU responsibility or tailored to each Member State?

6.1 Introduction

There is growing consensus that human-induced climate change and biodiversity loss are major driving forces of many social, economic, ecological and political issues, which society currently faces. These problems are set to increase (Pörtner et al., 2021). The two global crises – climate change and biodiversity loss – are strongly coupled. The one drives the other, and together they accelerate and exacerbate societal impacts (Richardson et al., 2023). Acknowledging this, the EU is leading the way globally in setting ambitious targets to tackle climate change and restore biodiversity.

The EU ambitions for climate and nature each come with land use requirements, which can either synergise or conflict. Examples of synergies between climate and nature outcomes include: 1) using wind farms in combination with farming (Unger and Lakes, 2023), 2) diversifying crops for improving natural pest and disease regulation (Juventia et al., 2021; Homulle et al., 2024), 3) or increasing soil organic carbon (Beillouin et al., 2023). Examples of trade-offs occur especially on highly productive agricultural land, where it may be more desirable to have fields and farms dedicated to agricultural productivity (Van der Werf & Bianchi, 2022), while planning a patchwork mosaic of nature at landscape level between farms (Tscharntke et al., 2022). See also dilemma 4. Synergies and trade-offs can also be addressed through demand-side interventions across supply chains, which can reduce the pressures on land use, e.g. through waste management or shifts in consumer behaviour (Van Zanten et al., 2023). See: Dilemma 5. Future land use scenarios on how EU climate and nature targets could be met, highlight that the window of opportunity to meet climate targets is closing rapidly and requires urgent action (IPCC, 2023). It is still feasible to meet nature targets if immediate, ambitious and integrated action is taken (Leclère et al., 2020). Land use ultimately will depend on how overall EU targets are allocated across Member States. Should efforts to reach these targets be shared equally across Member States? Or are there more strategic opportunities to leverage specific geographical, biophysical and socio-economic qualities of a country or area? And if so, how would this be governed? These questions and dilemmas will need to be transparently negotiated in decision making processes.

6.2 The importance of dilemma 3

Food and non-food biomass production systems are one of the major drivers of climate change and biodiversity loss. Ironically, the systems are also one of the first and major victims of these very crises (DeClerck et al., 2021). Europe has been warming more than twice as fast as the global average, making it the fastest warming continent in the world according to the World Meteorological Organisation (WMO). There is mounting evidence of the impacts of climate change, across the EU, including mortalities from excessive heatwaves (Arsad et al., 2022), flooding (Dankers & Feyen, 2008), droughts (Gudmundsson & Seneviratne, 2016), and wildfires (El Garroussi et al., 2024). This has had substantial knock-on effects in the food and non-food sectors – and is expected to increase in both frequency and severity.

Activities in the EU also drive climate change and biodiversity loss beyond its territories. As made clear in Dilemma 1, the EU relies heavily on feed imports (20% of all proteins) and thereby externalises 20-50% of its GHG emissions beyond its borders (Sandström et al., 2018). The resulting deforestation of the world's tropical forests releases large amounts of carbon into the atmosphere, loses valuable carbon storage capacities, and has a substantial impact on global biodiversity loss (tropical forests represent some 10% of the world's terrestrial biodiversity).

Within the EU, the condition of ecosystems – largely unfavourable and not improving – is also substantially affecting biodiversity loss (Maes et al., 2020). As much as 60% of soils in Europe are considered degraded (Cavallito, 2023). A mere 14% of forest and grassland ecosystems are in a favourable conservation status and considered capable of supporting viable species populations. Only 2-4% of primary and old growth forests – representing a major carbon sink – remain in Europe

(Maes et al., 2020). Concerningly, 83% of grassland habitats that depend on agricultural management are in an inadequate conservation status, thus eroding valuable ecosystem services on which biomass production depends (e.g. maintenance of soil nutrient cycling, soil moisture content, drought and flood regulation, pest and disease regulation, and heat regulation).

6.3 Questions for the EU dialogue

Related to climate

The European Climate Law has set a target to reduce net greenhouse gas emissions, by 55% by 2030 and 90% by 2040, relative to 1990. The management of land-based emissions and removals offers a substantial contribution to this target. Tanneberger et al. (2017) identified several land use opportunities to reduce sources of GHGs and enhance sinks. Degraded peatlands are a large land-based source of CO_2 emissions, comprising some 5% of the EU GHG emissions. Over half of EU's peatlands are degraded by drainage and used for agriculture, forestry and peat extraction. When drained, peatlands release large amounts of CO_2 into the atmosphere – rewetting returns them to carbon sinks. Further reductions can be achieved through reducing livestock and over-consumption of meat (see: Dilemmas 2 and 5). Ruminant livestock (cattle, buffalo, sheep, and goats) and manure are the primary source of methane emissions, which comprise 6% of the total EU GHG emissions. GHG emissions from nitrogen dioxide (comprising 4% of total GHGs) can also be reduced by managing soil and manure.

Contributing to the European Climate Law, the Regulation on Land Use, Land Use Change, and Forestry (LULUCF) sets net carbon removal targets and monitoring standards for all land-based emissions and removals to achieve by 2030 – both at EU and Member State level. It is also complemented by various other laws concerning land use in the agricultural, forestry and environmental sectors (e.g. the CAP, the Soil Monitoring law, the Forest Strategy and the Nature Restoration law).

The effort to achieve net carbon removals is shared between Member States on the basis of their historical contributions to net removals and their share of total EU managed land area. General flexibilities under LULUCF are also allowed through the Effort Sharing Regulation which, under certain conditions, allows trading of carbon budgets between Member States, as well as banking and borrowing between years within Member States – at least until 2029. The substitutability of carbon – where a molecule in one place can be replaced by another somewhere else – makes these transfers of goals possible for climate. These transfers imply targets can be set at the EU or global level and countries can contribute to those targets, to the extent that they can be achieved in the most effective and cost-effective way, with compensation agreements between countries. For years already, the EU Emission Trading System (ETS) has allowed companies and organisations within the EU, along with a few other European countries, to trade emission allowances as part of efforts to reduce greenhouse gases (GHGs). While this system offers flexibility, it is often quite complex, while laden with regulations (Tang et al., 2020, in: Bos et al., 2024a, p. 29). Implementing it requires numerous agreements and rules, which can slow progress. Additionally, these trading systems can lead to trade-offs and new dependencies. For instance, large-scale forest planting, while seen as a climate-effective strategy, can have detrimental effects on biodiversity and increase wildfire risks (Bos et al., 2024a, p. 29).

A key question for the dialogue is how climate goals could be allocated and/or traded among Member States after 2030? This can very much impact the way land is developed for both agriculture and nature in the EU. For example, if EU Member States were able to differentiate their goals as part of efforts to achieve climate neutrality, this could – on the one hand – have profound implications on the permissible intensity of livestock and arable agriculture across Member States (Lesschen et al., 2020). On the other hand, livestock intensification or de-intensification can also have profound knock-on effects for food and nature outcomes, depending on where this occurs.

Related to biodiversity

The EU Biodiversity Strategy for 2030 aims to protect 30% of the EU land area, with 10% of this under strict protection. With 26% of EU land area already in protected areas, the emphasis in the EU has shifted to restoring landscapes inside and outside of protected areas to support a climate-proofed and effective nature network for reversing biodiversity loss in Europe. Such a nature network requires connected semi-natural habitats to facilitate species mobility, especially in the face of climate change. This necessarily spans Member States borders and requires strong cooperation. Restoring such connectivity includes interventions such as blue-green veins in the landscape (Ortega et al., 2023), which can be supported by restoring habitats along river corridors or providing semi-natural landscape elements in agri-ecosystems (Stoffers et al., 2024).

The Nature Restoration Law sets an overall EU target to achieve restoration measures in at least 20% of the EU's land areas by 2030, and in all ecosystems that need restoration by 2050. It is estimated that up to 15% of this restoration would occur within agri-ecosystems and forests, with the remaining from restoring natural ecosystems and urban areas (Article 9 and 10 of the Nature Restoration Law). This translates into restoration activities in approximately 40 million ha of farmland or managed forests.

Where to place these nature restoration activities, mindful of production trade-offs, is still a matter of debate. Unlike carbon, nature and biodiversity are not perfectly substitutable. In removing a forest, for example, there will undoubtedly be non-substitutable components, e.g. identity of place, aesthetic or spiritual value. It is also not possible to trade biodiversity targets among Member States that have unique habitats and species, whose continued existence depends on the protection offered within those Member States. In addition, a certain baseline minimum environmental standard is required to prevent the collapse of ecosystem functioning and the delivery of ecosystem services, essential for food and non-food production. However, questions are raised around what extent we should set this minimum environmental baseline, and over what time horizon. Biodiversity benefits tend to require long term time horizons, and tensions occur when decisions are made according to short term needs and political cycles. Tensions also occur around what constitutes a basic need and how much we should be managing demand (Dilemma 5) – as this will have implications for how land is used.

A recent integrated assessment by Chapman et al. (2024) showed that it is possible to meet the 15% nature restoration targets outside protected areas and urban areas, without constraining current or future food and timber production (as per the Fit for 55 EU policy package). The study also found that pursuing both restoration and production requirements together – with equal share of targets among Member States – could improve the conservation of species by 23-42%, while also increasing land-based carbon stocks (1-4%). Such integrated land use planning provides the opportunity to prioritise restoration areas that least coincide with food and timber production needs. Allowing a more uneven allocation of targets among Member States, could further increase the conservation status of 4-9% more species.

This leads to a key question for the dialogue. In a scenario of uneven sharing of restoration responsibility, where trading systems for nature are not particularly useful, how would multi-lateral agreements between Member States work? And is it worth pursuing such protracted negotiations and convoluted rules and regulations for a more favourable outcome on only 4-9% more species? If so, what type of governance arrangements could be put in place (e.g. borrowing from concepts such as ‘polluter pays’ or ‘capacity to pay’)?

7 Dilemma 4 | At what scale should food and non-food biomass production coexist with biodiversity and address climate targets?

7.1 Introduction

There is a large demand for land expected to produce the required biomass in the EU. At the same time, land will be needed to sequester carbon and improve biodiversity (see: Dilemma 3). The current ambitions of the EU already require a large area of land. First, the ambitions to increase the carbon sinks by 310 Mt CO_2eq towards 2030 (LULUCF) with an increase of 3 billion trees, translates into a total of about 1 Mha of afforestation. Second, restoring 20% of degraded lands (of which approximately 15% is expected in lands for agriculture and forestry production), reduces the area that can be used for agriculture. Third, the ambition to have at least 15% of farmland under biodiversity friendly practices and 25% of farmland under organic agriculture, most likely reduces the amounts of biomass that can be produced. Yields of crops in organic agriculture are typically 20-25% lower than yields for mainstream systems (Seufert et al., 2012; Seufert, 2019). Another factor that reduces yields in organic farming is the need to grow legume crops for N input specifically into these farms, estimated to require an additional 25% of area (Van der Burgt et al., 2018). Combined, this means that a kg of organic food needs much more land, ranging from 130% (Connor, 2022) to 200% (Van der Burgt et al, 2021) compared to mainstream food products. Extra land is also needed for nature areas and the conservation of biodiversity.

Therefore, achieving the aims of nature together with food and non-food biomass production, leads to trade-offs between the desire to improve self-sufficiency for food, feed and biobased solutions for a circular economy. Questions arise on what could be the best compromise between competing land use claims? Are there land-use combinations possible that still produce the needed biomass for food, feed and resources in the EU? These questions are often framed in the context of the 'land sparing versus land sharing' debate about nature and biodiversity.

Trade-offs also exist between achieving climate targets and food production. For example, agriculture contributes to about 13.2% of total EU emissions and this share has increased gradually over time. About 5% of these total emission result from CO_2 emissions from peatlands (Greifswald Mire Centre, 2019). A total of 227 Mt CO_2eq stems from methane, and 136 Mt CO_2eq from N_2O (European Environment Agency, 2023c) and 220 Mt CO_2eq from peatlands (Greifswald Mire Centre, 2019, 2023). Enteric fermentation and manure are major sources of GHG emissions, together with peatland oxidation and denitrification in soils. Hence, the GHG emission reduction targets are also directly linked to the number of ruminants and volumes of manure in the system and the area of peatlands, predominantly used for pasture and grasslands. The GHG emission intensity varies widely across regions in the EU, where half of the agricultural GHG emissions comes from only four member states (France, Germany, Spain and Poland).

7.2 The importance of dilemma 4

Integrated crop and livestock options

The food, feed and non-food demands are influenced by consumer choices, and these determine the required crop- and livestock products. Hence a whole systems approach, which includes producers and consumers amongst others, is needed to assess alternative food, feed and non-food production options, and the outcomes for nature and climate. Choices will need to be made that also include importing from outside EU. Combining all targets within the EU, while not addressing food and non-food product demands, could result in an even larger externalisation of emissions. This will potentially have large net negative effects on global biodiversity and/or GHG emissions.

Next to GHG emissions, the agricultural sector also has major impacts on the EU environment, and strongly contributes to eutrophication and acidification of natural areas and water bodies. The largest nutrient balance surpluses are found in regions with large numbers of livestock, resulting from long-term and ongoing trends to further specialise, driven by the need to increase labour productivity (Schut et al., 2021). These excess nutrients originate from fertiliser and from feed imports, which end up in animal products and excreta.

The EU is strongly dependent on feed import for its animal husbandry sector, mainly in the form of soy from North and South America (Leip et al., 2015). Imported feed externalises environmental impacts of feed production, representing about 20-55% of GHG emissions by the agricultural sector (Sandström et al., 2018). This has major consequences for a wide range of ecosystem services, including biodiversity (Dreoni et al., 2022). Any measure to reduce emissions or increase biodiversity, should be evaluated in combination with its effects on domestic biomass production and imported biomass. This should account for the effects of imported emissions and biodiversity loss, outside the EU.

Hence, the production of animal feed and livestock form a major challenge for EU land use. Meeting the targets for nature, biodiversity, domestic and imported GHG emission reductions, combined with the increasing demand for non-food products, will require a reduction of feed imports and of livestock. This applies in particular for specific specialised regions with unresolved environmental issues. It affects the export of EU products derived from livestock, but also animal sourced food supply.

Several options to meet nature and climate targets, reduce dependency on feed imports, and meet food and non-food demand exist. Importantly, both demand-side and supply-side options require consideration. For example, on the demand side, a gradual shift to more plant-based diets has been shown to reduce the demand for animal products and achieve other emission targets (Leip et al., 2022; Van Selm et al., 2024). This option also strongly synergises with the ambitions to improve public health, which can be a catalyser for implementation. Options also exist on the supply side. For example, a system where crop and livestock are more strongly integrated in the region where crop and livestock specialists collaborate in exchanging products and land provides means, has many advantages. It improves the economic performance of crop and livestock systems within environmental constraints, may reduce environmental costs for society, and increase the share of local feed and especially protein production. Re-integration of crop and livestock systems enhances recycling of manure and reduce losses of nutrients within the system, and reduces the dependency on external resources, including feed and fertiliser (Delandmeter et al., 2024; Garrett et al., 2017). Such an integrated system is possible when crop and livestock systems are better balanced, for example by relocating animal production systems to areas dominated by crop production or underutilised areas, unsuited for food crops (such as grasslands on shallow soils, on heavy clay soils that are only suited for cereal crops or in mountainous regions). Re-introduction of livestock in such regions can have clear socio-economic benefits and increases landscape diversity in specialised regions that are currently dominated by only a few crops and large broadacre farms. For example, including grass leys, soy and other feed crops does not only diversify crop rotations, but also reduces N requirements and GHG emissions (Rotundo et al., 2024; Reinsch et al., 2021; Taube et al., 2023). Changing current farming systems in strongly specialised regions to more integrated systems, will encounter barriers and will have large socio-economic impacts with trade-offs (Garrett et al, 2017; Schut et al., 2021). For example, the required reduction of animal densities that can be supported by regional feed production has economic consequences for the animal husbandry sector, while growing more feed crops regionally may benefit crop growers.

Climate change, nature and biodiversity in lands managed for agriculture and forestry

Major sources of GHG emissions in agriculture derive from enteric fermentation, manure (CH_4 and N_2O) and oxidation of peatlands, used for agriculture with a lowered water level. In addition to a reduction in ruminant numbers (ruminants produce large quantities of methane), a widespread use of manure digesting technologies can reduce net GHG emissions. A second component of GHG emissions consists of the direct and indirect N_2O emissions from organic and mineral N applications. These emissions result from denitrification processes under anaerobic conditions, typically after heavy showers and during wet winter periods. These emissions can be reduced strongly by using good agriculture management practices, including precision agriculture approaches with the so called 4R principles (right time, right place, right type source, and right rate of fertilizers), and ensuring that N supply from soil matches N uptake from crops. However, emissions during the season increase exponentially with higher application rates as this results in higher N concentrations in soil water, during longer periods of time with larger loss risks. Emissions during the winter can be reduced by longer effective growing seasons, with crop uptake to transfer N from one season to the next (e.g. by cover crops).

The third major component of GHG emissions are peatlands. The EU has about 24.1 Mha of peatlands, with about 57% in use for agriculture or forestry (Tanneberger et al., 2017). These degraded peatlands need to be rewetted to reduce GHG emissions, with water levels increased to at least 20 cm below the soil surface to reduce oxidation. This has major consequences for land use and the intensity of the types of agriculture that are possible. Global biodiversity loss has not been halted or reversed, despite efforts to increase protected areas (IPBES, 2019). Similar to these global trends, current levels of biodiversity in EU agricultural areas are low and declining (European Court of Auditors, 2019), with many species under threat. Historically, the main driver of biodiversity loss in the EU was land use change. However, this has stabilised and in present day, about 78% of biodiversity loss is attributed to (indirect) effects of intensive livestock systems (European Court of Auditors, 2019; Leip et al., 2015).

There is fierce debate about how to address this, in what is often called 'land sharing' versus 'land sparing' strategies. Yet what is considered sharing at one scale, is sparing at another scale. For example, adding hedges and hedgerows on farms to increase biodiversity, takes some land out of production and the proportion may be quite high for an individual farmer. Yet this is considered as land sharing at regional scale and the proportion of land in this instance is relatively small (Grass et al., 2021). Also, it does not affect the intensity of land use between hedgerows, while at landscape level the intensity of land use is reduced. At global scale, neither a land sparing strategy nor a land sharing strategy is sufficient to meet biodiversity targets (Kok et al., 2023), emphasising the need to reduce human land use by also reducing demand for intensive livestock, such as a shift to more plant-based diets.

Major drivers of the decline in biodiversity are fragmentation of habitats, loss of heterogeneity of landscapes, loss of specific habitats and use of pesticides. Monoculture landscapes offer little variety in habitats and do not provide food and protection year-round. Field edges, hedges and wet landscape elements provide a particularly high diversity of habitats and are key to supporting genetic diversity (Grass et al., 2021). A mix of such elements in the landscape increases connectivity and provides redundancy of habitats which increases resistance and resilience of species present (Baudron and Giller, 2014). Biodiversity in these landscape elements provides a more important contribution to landscape biodiversity than do agricultural fields in simple landscapes (Baudry et al., 2003; Tscharntke et al., 2005).

Organic agriculture is less intensive than mainstream agriculture, as it is very restrictive in the use of pest- and fungicides and N from artificial fertiliser. The lower intensity and the more diverse system provides suitable habitats for e.g. insects and farmland birds, which are declining in numbers in mainstream farming systems. Organic yields are typically 20-25% lower compared to mainstream fields (Seufert et al., 2012; Seufert, 2019). The required N must be produced by grass-clover, lucerne, beans or other legumes on land, where produced N is a crop co-product. Specific crops such as red clover or lucerne, can produce N that can be used as fertiliser (Van der Burgt et al., 2021). However, these crops require land that cannot be used for something else. When combined, the required area nearly doubles for organic agriculture, when compared to mainstream agriculture.

Land sparing by setting land aside, either in large nature reserves or in patches in the landscape and on-farm, has been shown to support biodiversity. Setting aside land provides habitats for non-farmland biodiversity. Yet land sparing is only possible when biomass demand is reduced or when loss of agricultural production is compensated elsewhere, either through expansion of farmland, or through increased productivity. In addition, surrounding agricultural activity should not negatively impact the natural areas set aside. For example, pesticide drift, lowered ground water tables and nitrogen deposition from nearby farms are increasing eutrophication and acidification of ecosystems and negatively impacting biodiversity. To avoid these issues, extensification and farms with lower emissions are well suited for areas near valuable nature reserves to maintain biodiversity.

Land sharing, where intensity is reduced, and production and biodiversity objectives are combined on farmland, also increases biodiversity, and especially biodiversity that requires farmland habitats. Yet it seldom provides the same level of biodiversity as land set aside in nature reserves. Both sharing and sparing affect the productivity on current farmland, which needs to be compensated elsewhere. The biodiversity gain per unit of production lost is larger for land sparing than for land sharing. However, biodiversity is not a tradable commodity. Hence, in a region both land sharing and land sparing is needed to safeguard all habitats for biodiversity. Further, the pesticide and eutrophication pressures on habitats at landscape scale need to be considered, limiting the area that can be used for intensive agriculture within specific landscapes. This landscape context is very important. Biodiversity measures on single fields have limited effect, for example as shown for bird protection measured in isolated fields (Grondard et al., 2023; Kleijn et al., 2001). The benefit of predatory insects is related to the distance from the natural elements in the landscape (Bianchi, 2022; Bianchi et al., 2013), while the number of insects respond to a range of pressures in the landscape. Multifunctional landscapes require both land sparing and land sharing measures (Ekroos et al., 2016). Many animal species require a diverse landscape with a mix of habitats and respond to pesticide and other pressures at landscape level (Grass et al., 2021). For example, measures to protect farmland birds may be effective when applied by all farmers in a landscape, but not when done in a single field only (Grondard et al., 2023; Kleijn et al., 2001). A combination of low intensity grasslands, heterogeneous and patchy grasslands in a landscape are required to increase farmland bird numbers (Jeliazkov et al., 2016).

7.3 Questions for the EU dialogue

The trade-offs between biodiversity and the intensity of agricultural production are further complicated by the required reduction of GHG emissions. Each choice has consequences for land use and biodiversity. For example, taking peatlands out of production strongly reduces GHG emissions but also has obvious consequences for agriculture, while wetland habitats and associated biodiversity benefit. Reducing the number of livestock has clear benefits for both GHG and biodiversity, as much less land will be needed for feed production. Yet this should only be done when synchronised with a reduction in animal food demand to prevent externalisation of environmental impacts elsewhere in the world. Preferably, ruminants should only use land that is not suited for arable crops to reduce the food-feed and non-food competition. This does not mean that ruminants need to be reduced in all areas. In areas where NH^3 emissions are well below thresholds and soils are not suitable for arable crops, ruminants provide a valuable contribution to agriculture and associated communities. Pigs and poultry have quite a different role in the food system (De Boer & Van Ittersum, 2018; Van Zanten et al., 2019). Pigs can recycle and add value to food waste by utilising co-products from the industrial processing of agricultural products. Poultry can also utilise some waste-streams, or feed from insects living on waste-streams. Optimising pig and poultry numbers to the availability of waste materials, directly reduces the feed and hence land requirements. This reduces emissions associated with manure (see: Dilemma 2).

The various Member States differ in their biophysical environment and socio-economic positions. For example, there are clear differences in farm structures, production levels and animal husbandry. The options to reach targets for GHG reductions, nature restoration and agricultural biomass production differ between regions within and between Member States. There are regions where win-win-win combinations are possible. For example, in some regions of eastern Member States such as Poland, Estonia, Latvia and Lithuania, large yield gaps (yieldgap.org) and recently abandoned farmland offer opportunities to restore natural networks, and to use the land more intensively without major impact on the environment. In other parts of the EU, such as the Netherlands, Flanders, Brittany and Denmark, with small yield gaps and intensive land use combined with high animal densities, land conflicts quickly arise. There, clear trade-offs exist and difficult choices must be made with respect to land use for intensive and extensive agriculture, protected nature reserves and blue-green veins with appropriate buffer zones.

The EU currently has a substantial opportunity to produce more biomass on current farmland, especially in eastern Member States. Part of this opportunity is needed to compensate the expected losses of production in southern Member States, considering the high risks of land degradation. Here, and elsewhere, the expected increase in variability of yields under rainfed agriculture in future climates, provides additional challenges for agricultural production. Current production in many areas is supported by irrigation, made possible by reliable river flows fed by both rain and meltwater. Meltwater flows are expected to decline and consequently rivers will depend more strongly on rainfall, with the disappearance of glaciers in the Pyrenees and the shrinking glaciers of the Alps. Hence, the water sources for irrigation are very likely to become more variable in the future, and agricultural water use for irrigation is increasingly in conflict with other demands in dry years, increasing risks for famers. With increased risks of crop failure, the required increase in agricultural intensity for higher yields, needed to produce the demanded biomass, may not be possible.

With increased risks of crop failure, the required increase in agricultural intensity for higher yields, needed to produce the demanded biomass, may not be possible.
The ambitions to increase resource autonomy and self-sufficiency in the EU for food-feed and non-food products, can conflict with the ambitions to set more land aside for nature and to reduce GHG emissions within the EU and from outside the EU, by reducing externalised emissions.
Considering these trade-offs and conflicting demands on land use, what should have priority? Should the EU prioritise actions for hotspot areas such as peatlands, to increase the impact of measures to reduce GHG emissions? Should the EU incentivise re-integrated crop and livestock systems and if so, at what scale? Can a shift in diets and a reduction in the demand for animal-based products be synchronised with the increase in EU biomass demands for non-food products, to prevent land-use conflicts?

8 Dilemma 5 | To what extent should policies intervene in consumer behaviour?

8.1 Introduction

Production and consumption are intrinsically connected. Achieving a transition to a sustainable food and non-food system requires a comprehensive transformation across the entire ecosystem, which includes changing consumer behaviour. To establish a resilient system, it is crucial that not only the production side evolves. Consumers and all parties involved in supporting consumer decision making, need to play their part too.

The role of consumer behaviour in agri-food systems has already been noted in earlier IPCC reports. For example, Garnett et al. (2015, p. 82) state that 'production-side measures, while important and necessary, cannot by themselves address the interconnected health and environmental challenges we face. Our consumption patterns also need to change'. According to the FAO, sustainable diets have a low environmental impact, promote food and nutrition security, and support a healthy life for both present and future generations (Burlingame & Dernini, 2010). Therefore, promoting sustainable diets also links to health outcomes.

Although countries and regions are confronted with distinct challenges, in general, more sustainable and healthy diets are required. Sustainable diets, for example, lean towards more plant-based and vegetarian diets, and to more local and seasonal diets (Tilman and Clark, 2014; Clark and Tilman, 2017). As the global population increases, along with urbanisation and rising wealth, the impacts of current dietary patterns are expected to grow (Van Dijk et al., 2021). Therefore, transitioning to healthier and more sustainable consumption patterns is essential. Transitions needed will also differ in different regions of the world. For example, protein consumption reflects differences from addressing malnutrition in low-income areas to reducing overconsumption and environmental impact in high-income regions (Adesogan et al., 2020). Yet this presents substantial challenges. Products must not only be sustainable, safe, affordable and nutritious (food), they also need to be accepted by consumers. Consumption behaviour is often shaped by deeply ingrained preferences and habits. The interplay between consumption, individual behaviour, and various social, cultural, and economic factors – such as status, social norms, the food environment, emotions, demographics, and financial status – is intricate, non-rational and complex (Michie et al., 2011; Onwezen & Dagevos, 2023).

In addition to the focus on consumer behaviour in relation to food, overconsumption relates to a wide range of behaviours. Sustainable lifestyles, including non-food consumption patterns, need to be taken into account too. We explain this using the example of clothing, because the influence of consumer behaviour is strikingly visible for textiles. The trend of fast fashion has led to a decrease in the average number of times a garment is worn by 38%, and a doubling in clothing production between 2000 and 2015 (Ellen Macarthur Foundation, 2017). A shift towards more sustainable consumption patterns is needed. How and to what extent should we intervene to motivate consumers to make more sustainable and healthier choices in various purchase settings?

8.2 The importance of dilemma 5

Current consumer behaviour patterns significantly influence our climate, the environment, biodiversity, and consumers' own health. The most prominent aspect related to food, is the high amount of animal protein intake (Willet et al., 2019). Animal source foods are a major component of food and especially protein intake in most EU diets. Many EU consumers eat more proteins than recommended (Onwezen et al., 2024). The dietary culture in the EU shows an animal-based eating culture, including meat and dairy products such as cheese and yoghurt. Furthermore, the current food consumption habits in the EU tend to be unhealthy, with excessive levels of fat, sugar, and salt (e.g. Breda et al., 2020). Concerning non-food consumer behaviour, one important example is the rising amount of textile fibres consumers use each year at global scale. This number has increased from 9.3 kg/pp in 2000, to approximately 15.5 kg/pp in 2025 (Textile Exchange, 2023).
Product prices frequently fail to accurately reflect their true social and

environmental costs, as many of these costs are externalised, and thus not included in the price consumers pay. This results in supply chain partners and consumers lacking the necessary incentives to shift towards more sustainable options. However, sustainability targets differ per region. E.g. an environmental problem in one country, does not necessarily have to be an issue in another part of the EU. Moreover, sustainably produced food can also cause potential trade-off issues such as increased land use and emissions as well as yield inefficiencies. Similarly, the non-food system has substantial external costs. For textiles, these are not only related to the use of fossil feedstock and related climate effects, but also to dumping of discarded clothing, e.g. in Africa.

Public steering of consumer behaviour, particularly in the realm of nutrition and fashion, is a socially and politically delicate matter. Consumers enjoy a degree of choice, often supported by quality labels and certifications such as the EU organic logo. While these labels can be informative, their influence on overall consumption patterns is limited and they mostly target specific, already motivated and informed groups (Onwezen et al., 2021).

More significant government interventions, such as taxes on meat, fat, and sugar, are likely to face opposition. The food environment is an important factor in steering consumer choices, and it is well-known that consumer behaviour is already influenced by marketing in our current food environment. The food environment currently encourages unhealthy, unsustainable choices, often due to the quantity of products on offer, and marketing attention in promoting the products, options and recipes, etc. (Onwezen et al., 2024; Poelman et al., 2021). The mainstream food market is often based on animal-based proteins. Advertising and store layouts contribute to shaping consumer preferences for high-fat, high-sugar, and high-salt foods. For years, supermarkets have employed special meat promotions to attract customers, leading them to purchase additional items that yield higher profit margins. Concerning textiles for clothing, the fast fashion trend is strongly influenced by social media, which especially targets adolescents (Open Access Government, 2022).

Societal factors such as climate impact, biodiversity, and health considerations are frequently overlooked when consumers are faced with choices in supermarkets or dining out, buying clothes online, or in a store. Instead, more individual and short-term values such as price and convenience drive purchasing decisions. Furthermore, all kinds of (often) unconscious drivers play an important role, such as emotions or the social and cultural environment. Consumers are not aware of all the many direct and indirect sustainability effects of their consumption patterns, and do not consciously weigh all pros and cons for each decision. Thus, minimal public intervention is unlikely to lead to the sustainable and healthy food and non-food system we aspire to achieve.

Hence, interventions are needed to support consumer behaviour towards more healthy and sustainable diets (Fresco & Poppe, 2016; Pyett et al., 2019; Van 't Veer, 2017, in: Bos et al., 2024a; Onwezen & Dagevos, 2023). To ensure that interventions are effective at shifting behaviours, they should be tailored to specific target groups, and address the barriers to change, such as consumer preferences and motivations, the environment and the capabilities of consumers to change (Michie et al., 2011). The hesitation to intervene in our food choices stands in stark contrast to the commonly accepted use of pricing strategies to reduce demand for fuels, as well as tobacco and alcohol. On the other hand, there is also societal support for more active government interventions to stimulate healthier and more sustainable consumption patterns. To truly progress towards more sustainable and healthier consumption patterns and habits, we must address whether we are prepared to adopt a more interventionist approach to shift the patterns. This could involve direct measures such as behavioural interventions, communication strategies, pricing incentives, informative labelling, regulations, and bans, or indirect strategies such as binding agreements with the agri-food sector and supermarkets. The Nuffield intervention ladder is often used as framework by researchers, in which 'soft' interventions such as information (campaigns) move up to 'harder' interventions, such as restrictive legislation and regulations (Nuffic Council on Bioethics, 2007). The interventions on supporting more plant-based diets are currently mostly related to monitoring and informing. The EU strategy for circular and sustainable textiles (2022) and the Eco-design for Sustainable Products Regulation are already moving up the intervention ladder, showing more actions to intervene and support the decrease of fast fashion (European Commission, 2024b).

8.3 Questions for the EU dialogue

While there are still gaps in our understanding, considerable experience has been amassed regarding interventions and communication strategies aimed at supporting more sustainable and healthy consumption patterns. Examples of these strategies include public awareness campaigns, sustainability labels, educational initiatives, and subsidies or taxes on unhealthy products. Information provision and education are among the most common and least controversial policy options for behavioural intervention. Research generally shows that information is a necessary condition for behavioural change, but in itself is ineffective to ensure actual behavioural change. A combination of different interventions, for example information about the consequences of meat consumption in combination with preparation tips and price differences between and/or different composition or positioning of the plant-based offering, has a greater chance of achieving intended behavioural effects, than single (and once-off) interventions (Macura et al., 2022; SAPEA, 2020).

While changes in consumer patterns are needed to respond to the current health and sustainability challenges, the question remains how far the EU and its Member States should intervene in guiding consumer choices. And which fundamental values should guide these interventions? These questions are crucial to address, as the freedom to choose one's own purchase is often perceived as a social right and an individual responsibility. Nonetheless, from a public perspective, prices and advertising often encourage detrimental choices, leading to the question if marketing of unhealthy and unsustainable choices leaves sufficient freedom of choice. The belief that we should minimise interventions in consumer behaviour, assumes that individuals will make rational choices regarding sustainability and health. This perspective allows for significant consumer freedom. However, it raises the question whether consumers are consistently capable or willing to make informed decisions.

Should we decide to intervene publicly, a wide array of options is available, each differing in intrusiveness and effectiveness. A widely accepted, yet minimally controversial, approach involves behaviour-change campaigns. On the other hand, price interventions like specific levies (e.g. a meat tax) or bans can be effective, although they tend to stir political controversy. Many types of interventions often fail to consider the food environment in which people make decisions. Without initiatives aimed at reducing economic incentives for producing, offering, and promoting unhealthy food, a singular focus on individual consumer behaviour is likely to fall short. To genuinely alter consumer behaviour, we also need interventions that influence the incentives faced by market actors, such as producers and supermarkets. This could involve ensuring that prices accurately reflect the external costs associated with products (true and fair pricing) and promoting sector-wide sustainability agreements or collective changes to the product offerings in supermarkets and stores, while remaining compliant with legal restrictions.

The burden of proof for the effectiveness and impact of behavioural interventions, especially beyond informing and nudging, is either not available, modest or ambiguous. This holds true, especially when it comes to behavioural influence in the longer term and/or at population level, due to differences in receptivity to certain interventions between population groups (for example, varying in dietary expertise or socio-economic position). Technology could also play a significant role in the transformation. For example, personalised dietary programs utilising biometric data can assist individuals in making more sustainable and healthier choices, while shopping.

Ultimately, whether we choose a more interventionist path or a more hands-off approach, we must recognise that our consumer behaviour is linked to health and sustainability and that support is needed when more sustainable and healthy consumption patterns are desired.

This all leads us to the following key questions, of which some have also been formulated in previous dilemmas. Who is responsible for our EU consumption habits? Is not intervening by the government an option at all? Is the consumer seduced too much into unsustainable or unhealthy consumer behaviour, with respect to over-consumption such as fast-fashion and diets with high animal-based proteins, fat, sugar and salt intake? Or do consumers receive sufficient information and opportunities to make healthy and sustainable choices on their own? How do we balance an individual's freedom of choice – such as 'the right to barbecue' – with the collective costs to society, now or in future generations? Are we willing to raise prices for unsustainable and unhealthy products? To what extent do strong consumer behaviour interventions align with the functioning of the EU, founded on representative democracy? In the end, the question pops up if we need to shift our policy from agricultural productivity to a more holistic food/non-food system perspective, in which we strive to match production- and demand-side interventions?

9 Navigating the complexity

9.1 Navigating long term visions within a safe and just operating space

There are already a range of possible directions to explore in each of the dilemmas discussed. International agreements, the EU's foundation of an open-border economy, competing spatial demands within and between Member States, etc., all influence which options appear viable and which do not. However, it is important to not make these decisions in policy siloes. This is because the dilemmas outlined here are not isolated. On the contrary, their strong interconnection means that it is important to combine and consider all dilemmas and their interactions to advance the debate. See Figure 9.1. Any choices made within the context of one dilemma could limit the options available to address others, and steer that issue in a certain direction.

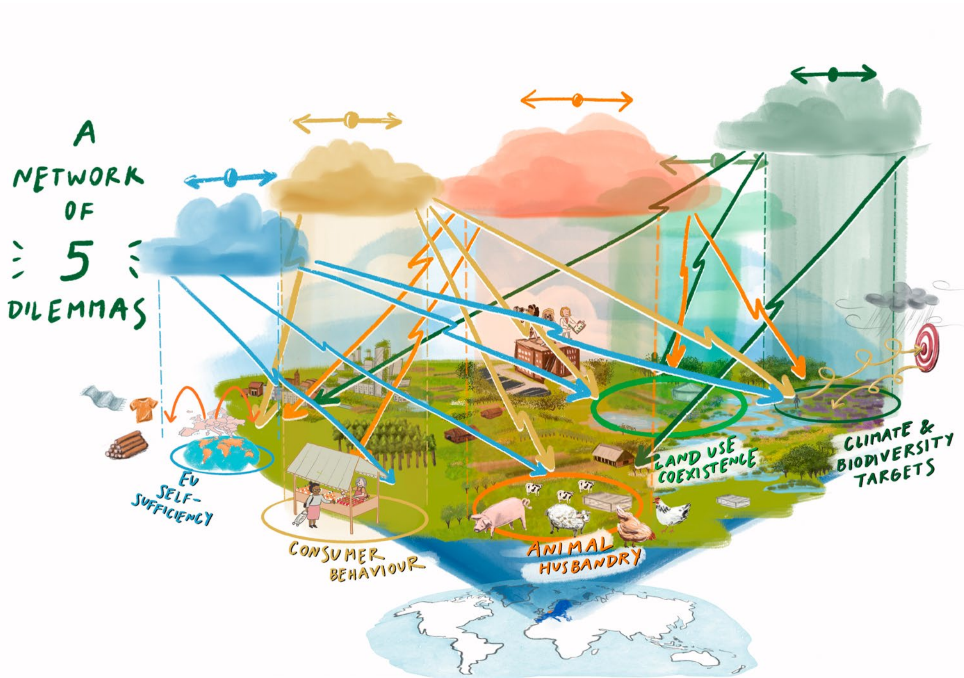

Figure 9.1 The dilemmas are interconnected – choices in one, will affect others.

These interactions make for complex outcomes – not easy to predict, with emergent, unexpected properties. The five dilemmas are linked in numerous ways. By way of illustrating this interconnectedness, consider the dilemmas posed on the extent to which the EU should strive towards self-sufficiency (Dilemma 1). Choices here will have large implications for the area of agricultural land required within the EU and its land-use intensity (Dilemma 4). This will have knock-on effects for achieving nature and climate goals in the EU and the world (Dilemma 3). And if the livestock sector primarily upcycles biomass not suited for human consumption and becomes a processor of co-products, residues and waste streams, the sector will become significantly smaller in a number of regions (Dilemma 2), which would contribute to nature and climate goals (Dilemma 4). All challenges and dilemmas concerning biomass production are inextricably intertwined with our consumption demand (Dilemma 5).

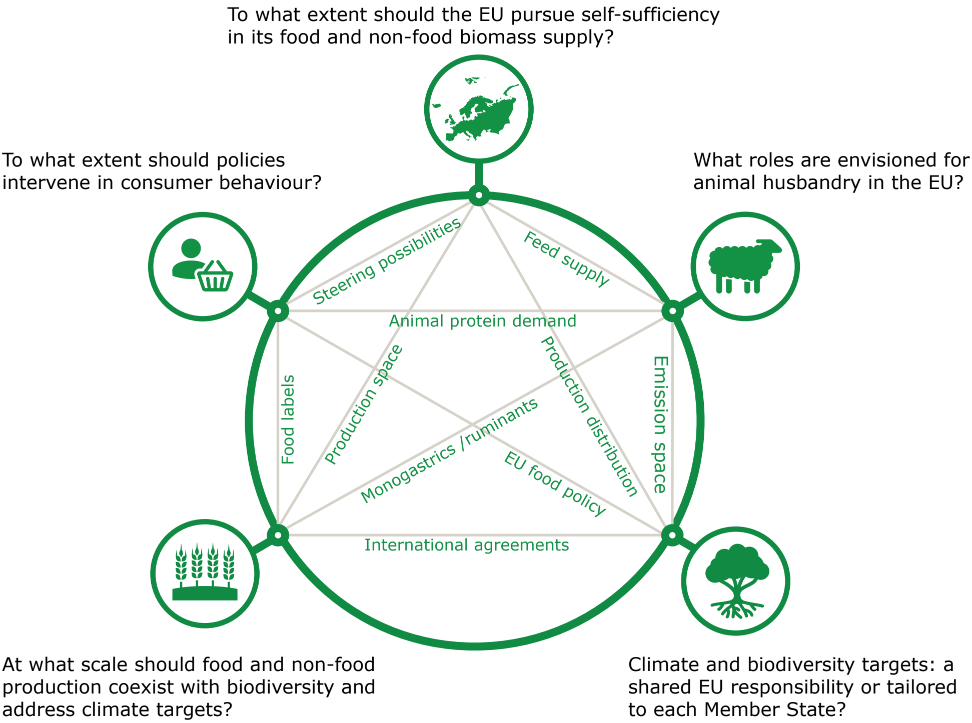

Figure 9.2 Links between the five different dilemmas.

It is important to strengthen capacities in science, policy and society to navigate these dilemmas holistically, and adapt as unpredictability emerges. The Safe and Just Operating Space is a bridging concept in sustainability science that sets the boundaries within which to navigate this complexity. The concept combines an environmentally safe boundary (Steffen et al. 2015) and a socially just boundary (Raworth, 2018), both of which have recently been quantified at a global level (Rockström et al., 2023). Together, these boundaries form the basis of the 'doughnut economics' model, essentially expressing that human activities should stay within planetary boundaries as well as ensure an equitable distribution of wealth and wellbeing among current and future generations (Raworth, 2018).

The Safe and Just Operating Space framing allows for the co-occurence of different pathways and perspectives towards the future, as long as they stay within the Safe and Just Operating Space (Figure 9.3). The room for manoeuvre will look different depending on the context. For example, the boundaries of physical systems may have already been reached in some contexts, with little further room for manoeuvre (e.g. in areas with excessive pollution of water or air that poses a risk to human health, or areas with high numbers of endemic species on the brink of extinction). In other instances, social or political circumstances may be more limiting, e.g. new international laws and regulations becoming more stringent, or the need to lift a population out of poverty.

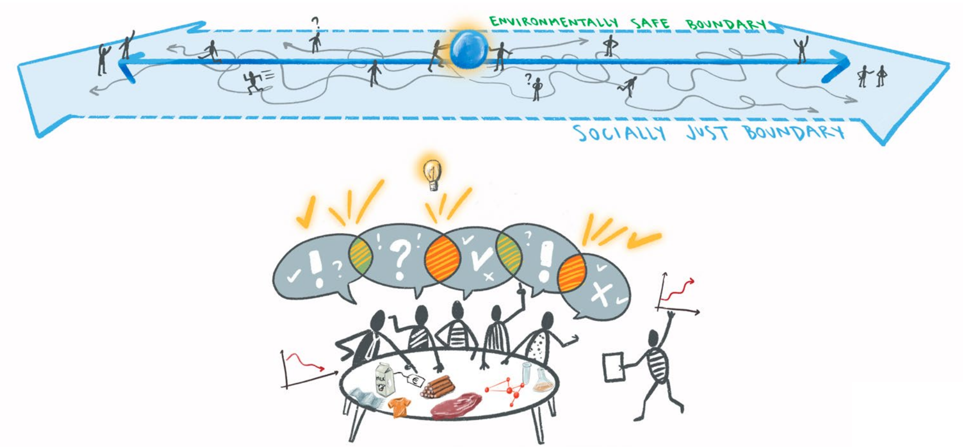

Figure 9.3 Maintaining multiple, interacting pathways within a safe environmental boundary and a socially just boundary over time, with iterative dialogue and negotiation to enable goal setting, experimentation, feedback, learning and adaptation.

Conceptualising pathways within a Safe and Just Operating space provides a long-term dimension and makes explicit that iterative dialogue and negotiation need to continue and evolve over time to continuously keep pathways within this room for manoeuvre, safe for the planet and just for humanity (Wise et al., 2014). Sharpe et al. (2016) notes that dilemmas within these pathways are not 'solved', but constantly 'resolved' through experimentation, feedback, learning, and creative innovation. This is enabled by policy mixes that balance regulation (disincentives) with adequate incentives to help de-risk the effects of change for the most vulnerable groups.

9.2 Fostering inclusive dialogue on the dilemmas

Choices to be made between the dilemmas have different sets of winners and losers, and are therefore profoundly political. A logical next step would be to use these dilemmas as a starting point for social and political dialogue. Most of the dilemmas will require balancing short-term demands with medium- and long-term visions, and costs of inaction. Because of the complex, unpredictable futures, a precautionary principle is advised. Furthermore, developing political and institutional-level capacity to systemically address long-term visions and needs is essential. It is important that different stakeholders and parties work together on strategic foresights to collectively assess the implications of alternative, future-focused actions and developments (scenario planning). As a way of delivering results that are broadly supported, alternative options will need to be openly negotiated with a broad set of stakeholders, both those with power to influence decisions for the future, as well as those whose everyday lives are affected by the decisions. There is growing realisation among science and policy communities that openly debating dilemmas and tensions is key to moving forward, even despite disagreement. To aid the dialogue process, a Dialogue Navigator has recently been developed, which outlines basic principles for creating a space to have a meaningful and inclusive dialogue, synthesizes just over 25 dialogue approaches, and provides guidance on which of these is most appropriate to the intended purpose of the dialogue and stakeholder context.

As outlined in the foreword to this report, the Strategic Dialogue on the Future of EU Agriculture showed that it is possible to reach agreements across the entire agri-food chain, despite polarized public debates. The proposed new platform offered as part of this process is a promising signal of the Commission's commitment to bring the whole of society along in debating these dilemmas and tensions, and thus learning together to shift mindsets, practices, and inform better policy and decision making.

Appendix A
Calculations on current and future use of demand for and supply of biomass

Biomass requirement for human food consumption

Human food consumption in the EU is calculated at 114 Mt of plant and animal based biomass. See Table A1.

- Food supply, expressed as carbohydrates, protein, fibres and fat and total energy is taken from FAOSTAT for the year 2021 (FAO, 2024).
- The food supply of different categories is multiplied by the energy content (in kcal per gram, using the Atwater system (Huel, 2024), and checked with the total energy supply.
- All food categories are converted to carbon, based on literature values and chemical formulas (Rouwenhorst et al., 1990; Zhao et al., 2017; Cheng et al., 2017).
- The total C supply (in gram per head per day) is multiplied by the number of days per year and the current EU inhabitants (449 million). Total C consumption is 53.6 Mt/year.
- Conversion from C to biomass is done by using the average C content of plant biomass of 0.47. Total biomass is 114 Mt.
- According to FAOSTAT, 69% of the energy supply comes from plant based food. Assuming a similar energy density of plant and animal-based food (Drewnowski et al., 2020) means that 79 Mt of plant biomass is supplied to consumers.

Part of this plant biomass is processed and coproducts are used as animal feed. The amount of coproducts for animal feed are incorporated in the feed requirement calculation.

NB: Food supply is not the same as the actual intake, as food loss and food waste are incorporated in the supply.

Table A1 Human food supply in the EU.

Category	Unit	Supply	Energy	Content	Results
			(kcal/gram)	(g/g)	
Carbohydrate (available) supply	g/head/day	353	4	0.44	
Dietary fibre supply	g/head/day	29			
Fat supply	g/head/day	143	9	0.8	
Protein supply	g/head/day	108	4	0.53	
Energy supply from statistics	kcal/head/day	3,193			
Energy supply calculated	kcal/head/day		3,134		
C supply calculated	g/head/day			327	
Average C content of biomass	(-)				0.47
EU inhabitants	head				4.49E+08
C consumption EU	Mt				53.63
Required total biomass	Mt dry matter				114.10
Energy supply from plant based food	%				0.69
Required plant biomass	Mt				78.73
Table A1 Supply of and demand for biomass for human consumption in the EU					

Source: own calculations.

The European population is expected to increase by about 1.5% in the coming decades and will decrease after 2040 (Eurostat, 2023a). So, for future projections, the same amount of plant biomass for food is used.

Biomass requirement for feed

Biomass for feed is approached in three different ways:

A)

The text from the FEFAC report (FEFAC, 2024) is used. Feed demand in the EU adds up to 644 Mt (see Table A2), consisting of 395 Mt roughages from farm origin, and 249 Mt of feedstuffs. The feedstuffs are partly farm grown cereals, single coproducts used as feed and almost 150 Mt of compound feed (FEFAC, 2024). It is likely that this amount is not all expressed as dry matter: compound feed and cereals are expressed on a product basis, being 85-88% of dry matter content. This makes it likely that this amount is an overestimation on a dry matter basis.

Table A2 Feed demand in the EU in Mt, 2020.

Data 2020	Amount
	(Mt)
Home grown roughages	395
Compound feed	150
Co products and single products	99
Total feed demand	**644**

Source: FEFAC, 2024.

The main components of compound feed are cereals (51%), cakes and meals (25%) and coproducts from food and bioethanol production (12%).

B)
To check the variable data from the series of FEFAC reports (in 2021 an amount of 827 Mt was reported, FEFAC, 2021), a second approach was chosen: the reported feed protein consumption of 84 Mt/y is combined with the assumption that overall protein content of animals rations is 14%. For monogastrics, this is often higher, which is also the case for many intensive dairy systems. This leads to 84/0.14 = 600 Mt/y as feed requirement. The authors of the FEFAC report mention a 45% share of protein coming from roughages which gives a total roughage amount of 250 - 290 Mt/y, assuming a 13 to 14% protein in roughage.

C)
A third approach takes the total animal production in the EU in 2022, expressed in Mt/y in Liveweight of animals and the amounts of milk and eggs, taken from FAOstat (2024) for Crops and livestock products. For meat, data have been converted from carcass to live weight, based on Opio et al. (2013). A feed conversion rate (FCR) has been assumed taken from FAOstat data (2024) and from Dutch farm analyses. The Dutch FCR figures for chicken, pig, milk and eggs have been multiplied by 1.25 to prevent underestimation of the feed requirement. The FCR for ruminant meat has been derived from Opio et al., 2013 and multiplied by 1.1. This third approach gives a feed requirement of 581 Mt/y. See Table A3.

Table A3 Estimation of EU feed requirements based on animal production and Feed Conversion Rate.

Product/Animal	Production	Assumed FCR	Feed requirement per species	Feed requirement, total
	Mt LW	kg/feed/kg LW	Mt/y	Mt/y
Cattle	12.22	17.60	215.11	581.38
Chicken	14.78	2.25	33.25	
Goat	0.16	17.60	2.81	
Pig	29.70	3.25	96.53	
Sheep	1.13	17.60	19.81	
Milk	153.63	1.33	203.55	
Eggs	6.34	1.63	10.31	

Source: own calculations.

The impression is that the estimate by FEFAC is relatively high. But the range lies between 581 and 644 Mt/year. For the overview in the main text a figure of 644 Mt/y has been chosen.

Future demand for biomass depends on the development of animal numbers. Cattle, sheep and pigs show a decreasing trend for the last decades, while chickens still show a constant increase in numbers (FAOstat). The EU agricultural outlook 2023-2035 (European Commission, 2023b) speaks about a continuing decline in pig meat production, while poultry is increasing. For sheep and goat a slight decline is expected. For dairy, no decline is mentioned explicitly. Although general trends are not very clear, the demand for feed biomass is kept constant.

Biomass requirement for fuel for transport

The current use of biofuels is 13 Mt oil equivalents (Mtoe) of biodiesel and hydrotreated vegetable oil (HVO), and 3 Mtoe of bioethanol. The 13 Mt oil equivalents represents 6.4% of the total need for transport fuels (IEA Bioenergy, 2023). For this, 16 Mt of oilseed crops, 3.5 Mt of cereals and 11.5 Mt of sugar beet are needed. Breakdown to oil, ethanol and co products has been taken from FeedPrint data (Vellinga et al., 2013). Yields have been derived from Eurostat (see section 2.3: production of biomass). Land requirement for the current production is 6.2 Mha. See Table A4.

Table A4 Biomass requirement for fuel for transport.

	Fraction	Volume	Weight	Kg/kg	Kg/kg	Required product	Yield	Req. land	Co-products
	%	million litre	Mt	oil	cakes	Mt	ton/ha	million ha	Mt dry matte
Rapeseed	0.38	4.94	4.31756	0.4	0.583	10.8	3.2	3.4	5.6
UCO	0.23	2.99	2.61326	1	0				
Palm oil	0.18	2.34	2.04516	0.2	0.4307	10.2	3.2	3.2	4.4
Animal fats	0.08	1.04	0.90896	1	0				0.0
Soybean oil	0.07	0.91	0.79534	0.19	0.78	4.2	2.6	1.6	2.9
Sunflower oil	0.02	0.26	0.22724	0.285	0.7	0.8	2.1	0.4	0.5
Biodiesel total		**13**	**11.44**			**26.0**		**8.6**	**13.3**

Source: own calculations.

	Fraction	Volume	Weight	Kg/kg	Required product	Yield	Req. land	Co-products
	%	million litre	Mt	ethanol	Mt	ton/ha	million ha	Mt dry matter
Wheat	0.14	0.42	0.3318	0.33	1.005455	5.9	0.2	0.4
Maize	0.36	1.08	0.8532	0.33	2.585455	7.2	0.4	0.7
Barley	0.03	0.09	0.0711	0.33	0.215455	5.1	0.0	0.1
Rye	0.03	0.09	0.0711	0.33	0.215455	4.2	0.1	0.1
Triticale	0.05	0.15	0.1185	0.33	0.359091	4.4	0.1	0.1
Sugar beets	0.38	1.14	0.9006	0.07803	11.54171	72.1	0.2	3.1
Cellulosic biomass	0.01	0.03	0.0237	0.1	0.237			
Bioethanol total	**1**	**3**			**15.9**		**0.9**	

Source: own calculations.

The transport sector is not only shifting to biofuels, but also to electricity, hydrogen and synthetic fuels. The latter are produced via Syngas, either from biomass of from fossil resources. When transport fuels would be replaced by biofuel only, the theoretical maximum amount of biomass for transport fuels would reach 500 Mt, or an equivalent of about 150 million hectare. The potential large demand gave rise to the discussion to consider the use of biofuels as an intermediate in the energy transition and not as a permanent solution (SER, 2020). The range for the coming decades is estimated at 50-250 Mt.

Fuel for energy production replacing fossil fuels

The biomass for energy production mainly originates from wood harvesting. The European Union harvested 510 Mm^3 of roundwood, of which almost 25% is used as fuelwood. In 2016, the contribution of fuel wood to the total energy consumption in the EU was 6%. Since 2016, the fuelwood production has increased by about 20%, which would bring the share of fuelwood in the total energy consumption to 8% (average in the EU) (Eurostat, 2023c).

The largest increase in renewable energy took place in the photovoltaic and wind sectors. However, the large fraction of fuelwood (40% of current renewable energy production) is raising concerns about the role of forests as a carbon sink and for biodiversity (European Environment Agency, 2024a).

The EU 2030 target for renewable energy of 42% (compared to the 22% in 2021) is ambitious and would imply doubling the current amount. A simple extrapolation would increase the demand for fuelwood from 125 Mm^3 of roundwood equivalents up to 250 Mm^3 of roundwood equivalents. However, JRC (2023) projects a fuelwood demand of 174 Mm^3 for 2050.

Biomass requirement for fibrous materials such as textiles, construction materials as wood and paper/board

The present global use of fibrous materials is summarised in the lower part of the following Table A5 (Bos et al., 2024b).

Table A5 Global use of carbon based materials, in Mt per year, 2021.

World-wide C-based materials and chemicals use per year (data circa 2021)		**Fossil based** Mt/y	**Bio-based** Mt/y
Materials	Plastics	368.0	2.5
	Thermosets	53.5	1.0
	Rubbers	14.4	12.8
Chemicals	Surfactants	6.3	10.5
	Solvents	25.1	12.0
	Fine chemicals	19.6	1.0

World-wide C-based materials and chemicals use per year (data circa 2021)		**Fossil based** Mt/y	**Bio-based** Mt/y
Fibres	Textiles	68.2	39.5
	Paper/board	0.0	420.0
	Timber	0.0	468.0
Total		**555.1**	**967.3**

Source: Bos et al., 2024b.

Textiles

The current global use of biobased textile fibres is almost 40 Mt of materials (mainly cotton) (Table A5). When shifting away from fossil based materials for textiles, an additional amount of almost 70 Mt of biobased materials is needed. To convert global data from the table, it is assumed that consumption in the EU is twice as much as the global average. This gives a current amount of 4.5 Mt of material and a future demand of 7.7 Mt. Converting present fossil-based textiles to future biomass use brings these amounts to a current demand of 9 Mt and a future demand of 15 Mt. Future total biomass for textiles will be 24 Mt from dedicated fibrous crops as flax, hemp and cotton, and regenerated fibres (viscose) from lignocellulose crops as bamboo and wood.

Wood, paper/board

The current demand in 2020 for roundwood used for construction and paper/board is 367 Mm^3 (JRC, 2024c), with an additional demand of 119 Mm^3 for fuelwood. Following the fair and SSP2 IPCC pathways, roundwood consumption is expected to be 374 Mm^3 and 471 Mm^3, respectively with an additional demand for fuelwood of 51 and 174 Mm^3, respectively. Import and export of wood are of limited importance and there is a net export of 2% of the roundwood production (Eurostat, 2024a).

Materials and chemicals

Materials and chemicals produced from biomass, currently equal about 40 Mt globally (see upper part of Table A5). When shifting away from fossil based sources, another 487 Mt will be added to this, totalling to 527 Mt. Converting this to the use in the EU and to the required biomass, this will amount to 9 Mt and 119 Mt for the current and future situation, respectively.

Production of biomass in the EU

- ***Land use***

  See Table A6. The Eurostat tables (means for the years 2018 up to and including 2022) indicate that utilised agricultural area covers 161.7 Mha, including 98.2 Mha arable land, 50.9 Mha permanent grasslands, 4.3 Mha temporary grasslands and 12.1 Mha with permanent crops. Wooded land covers another 158.7 Mha according to Eurostat (2024a). Camia et al. (2018) give a larger estimate of 182 Mha, of which 134 Mha is used for forestry and roundwood production (Camia et al., 2018).

- ***Biomass production***

Table A6 Biomass production in the EU in 2022.

2022					
Group	**Crop**	**Mt DM**	**Mt product**	**DM content**	**Production data**
Grass	Grassland	245		1.00	FEFAC, 2024
Feed/fodder	Green maize	85	243	0.35	https://ec.europa.eu/eurostat/en/web/products-eurostat-news/-/edn-20200210-1
	Pulses	3.7	4.1	0.90	EU cropdata_SE_Crops_311023_rev.xlsx
Cereals	Cereals	246	271	0.91	
Vegetables, fruit	Carrots	0.44	4.4	0.10	
	Onions	0.68	6.2	0.11	
	Tomatoes	0.92	15.4	0.06	
	Green legumes	27.7	277	0.10	
	Fruit	2.07	20.7	0.10	
	Grapes	2.86	23.8	0.12	
Sugar	Sugar beet	27.1	103.5	0.26	
Potatoes	Potatoe	16.6	48.5	0.34	
Oilseed	Rape	15.7	19.4	0.81	
	Sunflower	8.9	9.3	0.96	
	Soy	2.3	2.5	0.92	
	Olive oil	7.60	7.6	1.00	
	Other oilseeds	1.17	1.3	0.90	

Source: own calculations.

Future production

Agricultural production will be affected by a combination of factors. Desertification and land abandonment will reduce the agricultural area, together with urbanisation, afforestation and nature development. Future land productivity, where sustainable intensification in some areas will increase productivity and on the other hand, increased aridity will reduce productivity.

Loss of land by desertification and land abandonment

In the Southern part of Europe, especially the Mediterranean climate zones, effects of climate change are already impacting agriculture and forestry. The European Court of Auditors (2018) reported that in 2017 an area of 41.1 Mha was sensitive to desertification in Southern, Central and Eastern Europe (see Figure A1), which is 25% of the total agricultural area. This is an increase of 17.7 Mha compared to 2008.

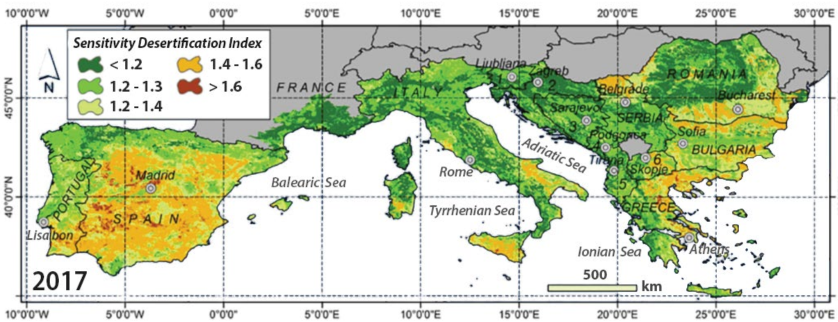

Figure A1 Desertification risk in 2017 in Southern, Central and Eastern Europe.
Source: European Court of Auditors, 2018.

Climate change is only one of the factors that may result in unused farmland. Land abandonment is another risk factor. The risk of land abandonment varies across the EU, but is high in specific areas, especially in Eastern parts of the EU, with about 5 Mha at risk of being abandoned by 2030 (Schuh et al., 2020). This could conceivably be re-integrated with stronger economic incentives.

Future land productivity

There are areas where current production exceeds environmental thresholds, especially in areas with a high concentration of animals, such as Denmark, the Netherlands, Flanders (Belgium), Brittany and the Po Valley (Italy) problems with air and water pollution occur. Although emissions have reduced, target values are not yet reached (European Environment Agency, 2024b). Furthermore, agri-chemicals including herbicides, pesticides and fungicides are threatening biodiversity and public health. Pesticide use has remained fairly constant over the last decade (Eurostat, 2024b). In addition, nutrient inputs are still too high in some regions of Europe, leading to poor ground- and surface water quality (European Environment Agency (2023a). In these areas reduction of biomass production in the future is likely, although the scale is difficult to calculate as this depends on many factors.

There are also areas with still substantial opportunities to increase yields on current farmland. Yields are well below reasonable yield levels in many areas of the EU, especially in eastern Member States. In north-west Europe, yields are much closer to their potential yield under rainfed conditions. Experts consider yield gaps of up to 80% are exploitable (Van Ittersum et al., 2013). Hence, crop yields at 80% of water limited yields are well possible and have limited impacts on the environment, when using good agronomic practises. We used a conservative yield estimate, based on 75% yield gap closure. With the current crop acreage, this would result in an increase of total biomass production from almost 700 to about 900 Mt/y DM. This does require substantially higher nutrient inputs, which should be derived from residual streams and green energy sources for nitrogen. Furthermore, it can be expected that land is used more intensively when prices for biomass are higher. There is still potential to further increase production on current land, e.g. by double cropping and relay cropping where the effective growing season is extended.

It needs to be noted that risks of crop failure and poor yields are increasing. In general, water availability becomes more problematic. Not only in the South of Europe, but also in other regions. The same report (European Court of Auditors, 2018) refers to studies showing an increase in aridity (drought) over large areas of Europe. See Figure A2.

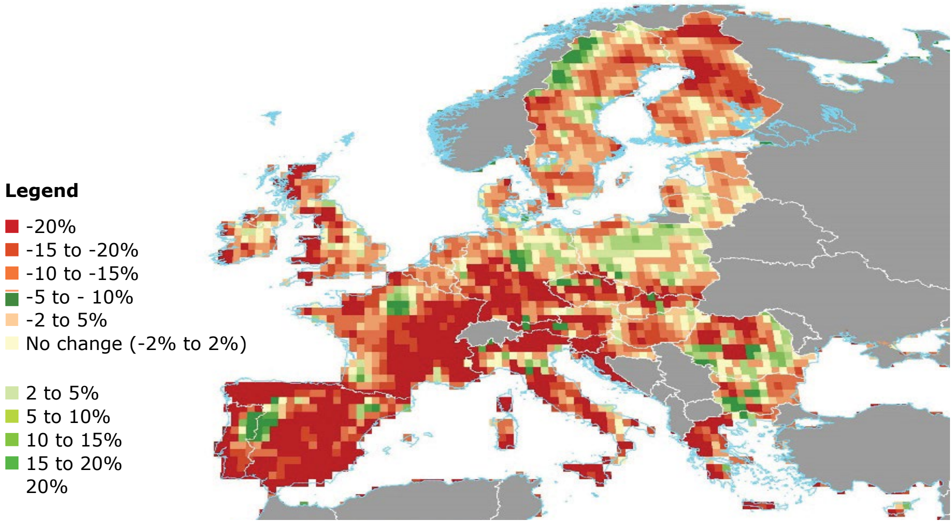

Figure A2 The predicted change in aridity index under the 2.4 C scenario in 2071 – 2100 compared to 1981 – 2010. Source: European Court of Auditors, 2018.

Both very wet and very dry seasons are expected to become more frequent. In combination with the decline of meltwater from glaciers in the future, river flows may be substantially reduced, which affects the opportunity to use irrigation from river water and from ground water courses. There is no clear overview at this moment on how this would affect future crop yields and cropping patterns.

Matching demand and production

Calculation approach:

- Production is 694 Mt/y, area is 160.2 million hectares. Data taken from the report. The average DM yield is 4.33 ton per ha.
- The current demand is 782 Mt/y, which means that 782 – 694 = 88 Mt has to come from outside the EU. Assuming an average yield for oilseeds and cereals of 3 ton of DM per hectare, an area of 29 million hectare is required.
- Future demand ranges between 915 and 1115 Mt/y, see chapter 2.
- Future production, a pessimistic scenario with 120 million hectare agricultural land left, without an increase in productivity and an optimistic scenario of 140 million hectares with a 20% productivity increase have been defined. The plant biomass production in these two scenarios is 520 and 727 Mt/y, respectively.

- This gives a gap between production and demand as shown in table A7, ranging between 188 and 595 Mt/y, being more than the double and the sixfold of the current gap.
- Converting the gap between demand and production to hectares outside the EU gives results of 63 to 198 million hectares.

This calculation contains high uncertainties and is a rough approach. But it gives a good impression of the order of magnitude of external land requirement to meet EU demand for plant biomass.

Table A7 Matching demand and production.

						Extra land needed outside the EU
Matching demand and production	**Demand**	**Production**	**area Europe**	**Demand gap**	**DMY RoW***	**area RoW***
	Mt		Mha	Mha	ton/ha	Mha
now	782	693	160	88	3	29
low demand, low production	915	519	120	395	3	132
high demand, low production	1115	519	120	595	3	198
low demand, high production	915	727	140	188	3	63
high demand, high production	1115	727	140	388	3	129

* **DMY** = Dry Matter Yield **RoW** = Rest of the World

Source: own calculations.

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