Agora
Agriculture

STUDY

Agriculture, forestry and food in a climate neutral EU

The land use sectors as part of a sustainable food system and bioeconomy

Please cite as:

Agora Agriculture (2024): Agriculture, forestry and food in a climate neutral EU. The land use sectors as part of a sustainable food system and bioeconomy.

Study
Agriculture, forestry and food in a climate neutral EU.
The land use sectors as part of a sustainable food system and bioeconomy.

Written by
Agora Agriculture
Anna-Louisa-Karsch-Straße 2 | 10178 Berlin
P +49 (0)30 700 14 35-000
www.agora-agriculture.org
info@agora-agrar.de

Project lead
Christine Chemnitz | christine.chemnitz@agora-agrar.de
Harald Grethe | harald.grethe@agora-agrar.de
Wilhelm Klümper | wilhelm.kluemper@agora-agrar.de
Nikolai Pushkarev | nikolai.pushkarev@agora-agrar.de
Blanka Stolz | blanka.stolz@agora-agrar.de

Authors
Emma André, Jaclyn Bandy, Arnaud Brizay, Christine Chemnitz, Tanja Dräger, Harald Grethe, Tom Hollander, Ivonne Kampermann, Wilhelm Klümper, Nahleen Lemke, Georg Lukas, Jakob Meemken, Wiebke Nowack, Cora Petrick, Nils Ole Plambeck, Nikolai Pushkarev, Christian Rehmer, Stephanie Wunder (all Agora Agriculture).

CAPRI modelling was conducted by Alexander Gocht and Torbjörn Jansson with technical support from Heinz-Peter Witzke, Davit Stepanyan, Jörg Rieger, Ferike Thom and Davide Pignotti.

Acknowledgements
We thank all persons who contributed through provision of data, analysis, intensive review or debates to this study. Among them are the members of the council of Agora Agriculture, colleagues from Agora Think Tanks, scientists from different universities and other research institutes and think tanks as well as stakeholder representatives from the agricultural, forestry and food sectors and civil society organisations.

Agora Agriculture is funded by alv Foundation, European Climate Foundation, German Federal Environmental Foundation, Porticus, Robert Bosch Stiftung, Stiftung Mercator and Umweltstiftung Michael Otto.

Preface

Dear reader,

The land use sectors agriculture and forestry are vital for societal well-being. They provide safe, nutritious food, and have large potential to increasingly contribute to a climate neutral economy, enhance biodiversity and environmental quality, as well as prosperity in rural areas.

While pathways to climate neutrality are well defined for many economic sectors, there is currently no integrated analysis of the potential of agriculture, forestry and food to deliver on sustainability objectives within the EU. This study contributes to closing this gap by presenting a scenario for the land use sectors as part of the food system and the bioeconomy in a climate neutral EU by mid-century. It also outlines policies that incentivise and value the contributions of agriculture and forestry to societal objectives and strengthen future-oriented land use sectors.

We developed this analysis over the past two years and engaged in intensive stakeholder dialogues with scientists, policy makers, administrators and representatives from the agricultural, forestry, food and bioeconomy sectors, as well as environmental and other civil society organisations. The constructive, solutions-oriented approach of all stakeholders involved helped shape our analysis.

We hope this study serves as a useful contribution to the discussion on the future role of agriculture and forestry as part of the food system and the bioeconomy, and we look forward to continuing the exchange.

Christine Chemnitz and Harald Grethe
Directors, Agora Agriculture

Key findings at a glance

1 **Agriculture and forestry can substantially increase their contribution to achieving climate neutrality, biodiversity protection, human health and other societal sustainability objectives.** However, this potential is hindered by an insufficient policy environment. A main roadblock for creating enabling policies has been the lack of a shared vision for the future of the land use sectors.

2 **By mid-century, agriculture and agricultural peatlands in the EU can cut their greenhouse gas emissions by 60 percent – in sharp contrast to their historically stagnating emissions.** Carbon removals can be increased in agriculture and be stabilised in forests. Biodiversity loss in agricultural landscapes can be reversed, while biomass production for the bioeconomy increases. This is possible while producing sufficient food, improving animal welfare, lowering agricultural imports and increasing agricultural exports, thereby contributing to global food security.

3 **Efficient land use and a more sustainable demand for food, feed and other biomass are the key levers for realising these sustainability potentials.** This requires economic incentives for the provision of public goods, such as carbon removals and biodiversity protection, which create opportunities for farmers and forest owners. Additionally, fair food environments for consumers can support and incentivise sustainable food consumption including more plant-rich diets and less food waste.

4 **The 2024–2029 EU legislative period is crucial, as it offers the opportunity to build an enabling policy environment.** Relevant components are an ambitious climate policy for the land use sectors, a Common Agricultural Policy that focuses on the provision of public goods, a legislative framework for sustainable food systems, an action plan for the efficient use of biomass in the bioeconomy and a European Rural Deal that supports rural areas in realising future economic opportunities.

Content

The **Annex** to the study is published as separate document and provides details about the data used, the quantitative model and the additional calculations supporting the study.

The Annex can be found here:
https://www.agora-agriculture.org/land-use-study-annex.pdf

List of abbreviations

AALU	Agriculture and Agricultural Land Use
AFOLU	Agriculture, Forestry and Other Land Use
AHAW	Animal Health and Animal Welfare
AKIS	Agricultural Knowledge and Innovation Systems
AMR	Antimicrobial Resistance
API	Application Programming Interface
bcm	Billion Cubic Metres
BEUC	Bureau Européen des Unions de Consommateurs, European Consumer Organisation
BioCCS	Biogenic Carbon Capture and Storage
BIOHAZ	Biological Hazards
BSE	Bovine Spongiform Encephalopathy
CAP	Common Agricultural Policy (of the European Union)
CAPRI	Common Agricultural Policy Regional Impact (model)
CBAM	Carbon Border Adjustment Mechanism
CBD	Convention on Biological Diversity
CCS	Carbon Capture and Storage
CCU	Carbon Capture and Utilisation
CEJA	Conseil Européen des Jeunes Agriculteurs, European Council of Young Farmers
CH_4	Methane
CLC	Corine Land Cover
CO_2	Carbon Dioxide
CO_2eq	Equivalent of Carbon Dioxide (the amount of carbon dioxide that would cause the same radiative forcing as the greenhouse gases in question)
COP15	15th Conference of Parties to the UN Convention on Biological Diversity
CRCF	Carbon Removals and Carbon Farming
DAC	Direct Air Capture
DACCS	Direct Air Carbon Capture and Storage
DIGITAL	Digital Europe Programme
dLUC	direct Land-Use Change
EAFRD	European Agricultural Fund for Rural Development
EAGF	European Agricultural Guarantee Fund
EASAC	European Academics Science Advisory Council
ECA	European Court of Auditors
EEA	European Environment Agency
ECDC	European Centre for Disease Prevention and Control
EFSA	European Food Safety Authority
EIB	European Investment Bank
EIP-AGRI	European Innovation Partnerships for Agricultural Productivity and Sustainability
EMA	European Medicines Agency
ENRD	European Network for Rural Development

eq	Equivalent
ESABCC	European Scientific Advisory Board on Climate Change
ESC	European Social Charter
ETS	Emissions Trading System
EU	European Union (here: EU-27)
EU-ETS	European Union Emissions Trading System
FADN	Farm Accountancy Data Network
FAO	Food and Agriculture Organization (of the United Nations)
FSDN	Food Security and Sustainable Development Network
FSFS	Framework for Sustainable Food Systems
GAEC	Good Agricultural and Environmental Condition
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GMC	Greifswald Mire Centre
GNB	Gross Nitrogen Balance
GW	Gigawatt
GWP	Global Warming Potential
ha	Hectare
HLPE	High Level Panel of Experts on Food Security and Nutrition
HWP	Harvested Wood Product
IASS	Institute for Advanced Sustainability Studies
ICESCR	International Covenant on Economic, Social and Cultural Rights
ICRC	International Committee of the Red Cross
IFAD	International Fund for Agricultural Development
ILO	International Labour Organization
iLUC	indirect Land-Use Change
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
JRC	Joint Research Centre
kcal	Kilocalorie
kg	Kilogramme
kg N	Kilogramme Nitrogen
KNE	Kompetenzzentrum Naturschutz Energiewende, Competence Centre for Nature Conservation and Energy Transition
KTBL	Kuratorium für Technik und Bauwesen in der Landwirtschaft e. V.
LSU	Livestock Unit
LULUCF	Land Use, Land-Use Change and Forestry
MFF	Multiannual Financial Framework (of the European Union)
MRV	Monitoring, Reporting and Verification
Mt	Million tonnes
N_2O	Nitrous Oxide
NDA	Panel on Nutrition, Novel Foods and Food Allergens
NECP	National Energy and Climate Plans
NH_3	Ammonia

NO_3^-	Nitrate
NRL	Nature Restoration Law
NUTS	Nomenclature of Territorial Units for Statistics (a geocode standard for referencing subdivisions of countries for statistical purposes in the EU, e.g., NUTS-2: Nomenclature of Territorial Units for Statistics, Level 2)
PV	Photovoltaics
SAF	Sustainable Aviation Fuels
SAPEA	Science Advice for Policy by European Academies
SDG	Sustainable Development Goal
SMEKUL	Sächsisches Staatsministerium für Energie, Klimaschutz, Umwelt und Landwirtschaft
SRC	Short Rotation Coppice
t	Tonne
TWh	Terawatt-hour
UAA	Utilised Agricultural Area
UK	United Kingdom
UN	United Nations
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
UNICEF	United Nations Children's Fund
WBAE	Wissenschaftlicher Beirat für Agrarpolitik, Ernährung und gesundheitlichen Verbraucherschutz beim Bundesministerium für Ernährung und Landwirtschaft, Scientific Advisory Board on Agricultural Policy, Food and Consumer Health Protection at the Federal Ministry of Food and Agriculture
WBD	Wissenschaftlicher Beirat für Düngungsfragen beim Bundesministerium für Ernährung und Landwirtschaft, Scientific Advisory Board on Fertiliser Issues at the Federal Ministry of Food and Agriculture
WBW	Wissenschaftlicher Beirat für Waldpolitik beim Bundesministerium für Ernährung und Landwirtschaft, Scientific Advisory Board on Forest Policy at the Federal Ministry of Food and Agriculture
WFP	World Food Programme
WHO	World Health Organization
WTO	World Trade Organization
WRAP	Waste and Resources Action Programme
WWF	World Wildlife Fund
yr	Year

Executive Summary

Introduction

Agriculture and forestry – the land use sectors – are crucial for attaining key sustainability objectives to which the EU and its member states have committed themselves. These objectives range from becoming climate neutral by 2050 to protecting biodiversity and advancing social and economic well-being. Agriculture not only produces food and other raw materials but also manages landscapes, shapes ecosystems, impacts animal welfare and has the potential to contribute to carbon sequestration. In addition to wood production, forests support an extensive range of ecosystem services, including carbon sequestration and storage, the provision of habitats, the protection of biodiversity, the retention of water as well as local cooling effects. Both sectors support livelihoods and provide economic value added. Our analysis takes these societal objectives as a starting point and shows the significant potential of the land use sectors, within the context of changes in demand for food, feed and other biomass, to contribute to their achievement.

While pathways to climate neutrality are outlined for many economic sectors, there is currently no integrated analysis of the potential of agriculture and forestry to deliver on the different sustainability dimensions within the EU. With this study, we intend to contribute to closing this gap. We present a scenario for the land use sectors as part of the food system and the bioeconomy in a climate neutral EU by mid-century. This scenario shows a strong contribution to climate neutrality, healthier and more sustainable food consumption, enhanced biodiversity and increased biomass production to replace fossil carbon across the economy. At the same time, animal welfare improves, and the EU becomes a net exporter of virtual agricultural land, thereby reducing the pressure on global land resources. Although this scenario is ambitious, it can be achieved if land is used efficiently, and if the demand for food, feed and other biomass is more sustainable compared to today.

This requires an enabling policy environment that creates economic opportunities for farmers, forest owners and rural entrepreneurs, as well as fair food environments for consumers. Among others, this includes addressing the challenge that providing public goods – such as biodiversity protection and climate change mitigation – often incurs substantial costs and is typically not remunerated by the market. This presents a challenge for farmers and forest owners facing international competition. Therefore, public payments are needed to adequately remunerate the provision of public goods.

Methods

The scenario we present in our study offers an integrated vision that considers the interactions between the land use sectors, the food system and the bioeconomy within the context of a global market for agricultural and forestry products. We outline one plausible future among many possibilities. Although other futures are conceivable, achieving results for a range of sustainability objectives simultaneously, we demonstrate the central importance of certain measures.

We set 2045 as the target date for our scenario to align with Germany's legal commitment to become climate neutral by that year. While the EU's legal target for climate neutrality is 2050, we consider the results of the 2045 scenario are also applicable to 2050, allowing an additional five years for implementation.

The outcomes presented in this study are the result of our analytical steps:

1. We analyse the current state of the land use sectors and food system, as well as the relevant EU policy context, in relation to societally agreed sustainability objectives.
2. We identify the most important levers for achieving sustainability objectives for six thematic areas, namely biomass for the bioeconomy, food demand,

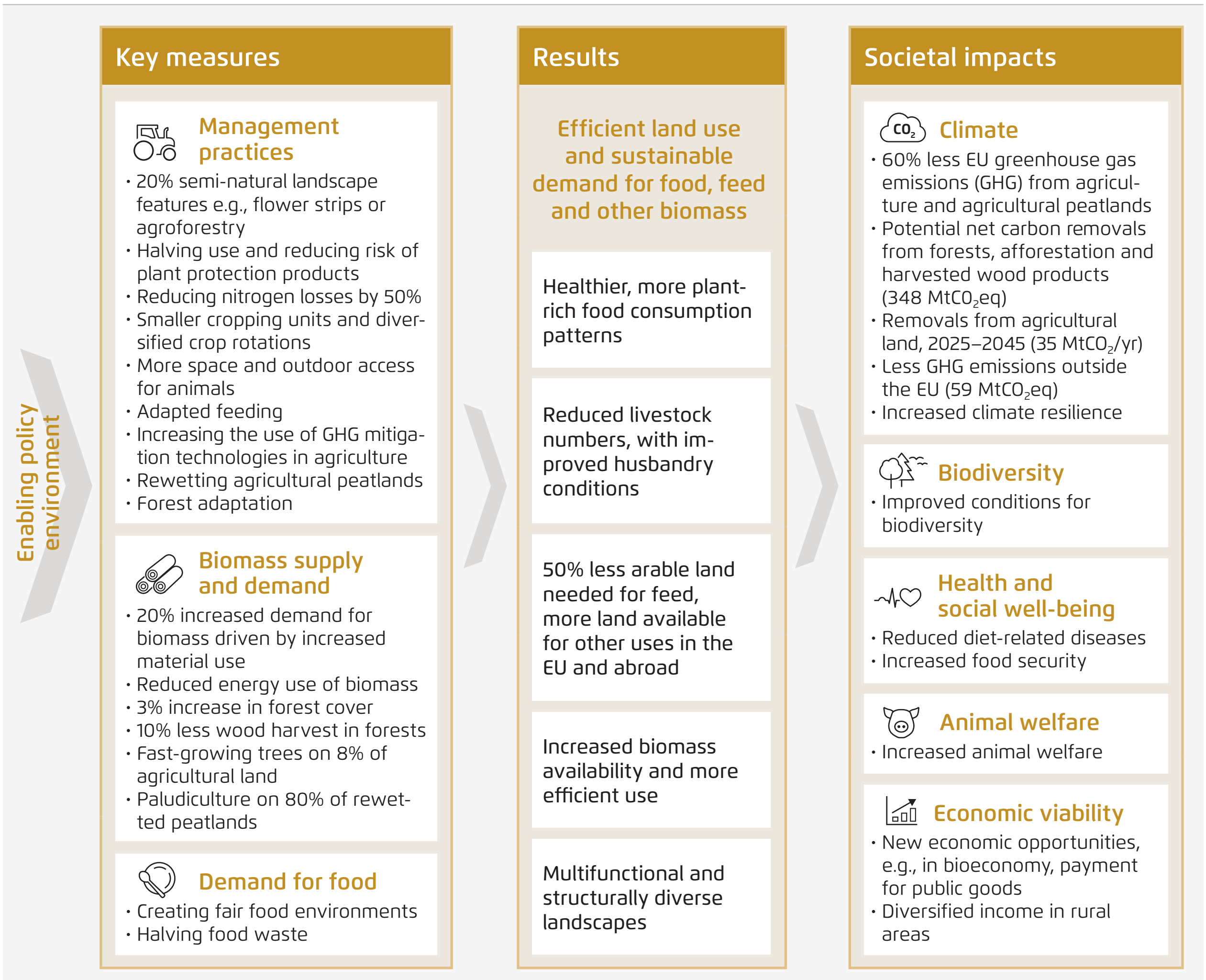
livestock farming, arable farming, agricultural peatlands and forests.

3. We outline a scenario in which EU agriculture and forestry – in the context of changes in the demand for food, feed and other biomass – make a significant contribution to societally agreed sustainability objectives. This scenario is largely grounded in quantitative analyses. For agricultural production and food demand, we use the Common Agricultural Policy Regionalised Impact (CAPRI) Modelling System, a global partial equilibrium model of the agricultural sector. Since CAPRI does not cover forestry, the scenario's assumptions about forest management and results are derived from additional calculations.
4. For each thematic area, we outline a set of policy options that we expect will support our scenario. We also propose five cross-cutting policy priorities for the 2024–2029 EU legislative period.

The scenario

Our scenario relies on two main building blocks: **efficient land use and a more sustainable demand for food, feed, and other biomass.** This combination allows for a substantial contribution to societal objectives (Figure A).

Key measures and resulting societal impacts → Fig. A



Agora Agriculture

Efficient land use: Land use fulfils diverse societal demands, ranging from the production of food, wood and other raw materials to the provision of habitats and other ecosystem services, such as carbon sequestration. However, land is limited in the EU and trade-offs exist between different land use objectives. Efficient land use is important to optimise returns under any given demand scenario, to mitigate trade-offs and to deliver multiple benefits simultaneously.

More sustainable demand for food, feed and other biomass: Different consumption patterns of agricultural and forestry products have different effects on climate, biodiversity and health. Adopting more sustainable food consumption patterns, such as increasing plant-based foods and decreasing animal-based products, can significantly impact these outcomes. In the scenario, a 50% reduction in the consumption of animal products by 2045 leads to a similar decrease in livestock production. This also reduces the demand for animal feed. In addition, a 50% reduction in food waste alleviates pressure on land resources and helps reduce greenhouse gas emissions.

Sustainable demand is also important for other biomass uses, such as for materials and bioenergy. In the scenario, we project the overall demand for non-food, non-feed uses of biomass to increase by about 20% by 2045. This is driven by an increase in the material use of biomass by about 70% to replace fossil feedstocks across the economy and a gradual shift away from using biomass for bioenergy production, which we assume will decrease by 15%, as electrification becomes available for a wider range of uses.

In the following paragraphs we highlight how our scenario contributes to different societal objectives:

Climate change mitigation

Greenhouse gas emissions from agriculture and agricultural peatlands decline by more than 60% by 2045 compared to 2020 (Figure B). This is substantial considering the only 2% reduction in emissions from agriculture and agricultural peatlands achieved between 2005 and 2020. The 60% decline is achieved due to emissions reductions in three main areas:

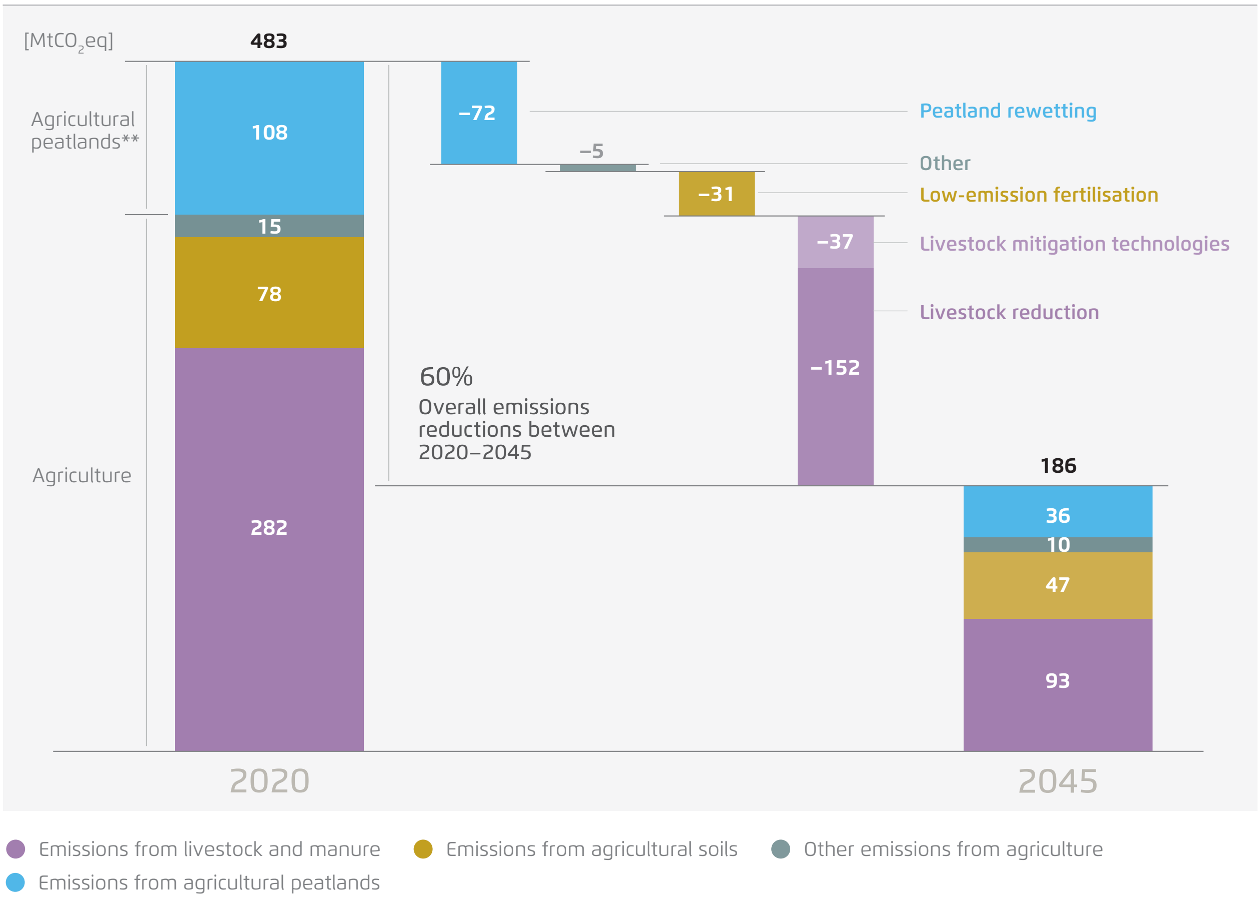
1. Emissions from livestock, including both enteric fermentation and manure management, decrease by about 67%. About 81% of this reduction is attributed to a reduction in livestock numbers. The remaining 19% result from the uptake of emissions mitigation technologies.
2. Emissions from agricultural peatlands decrease by 67%. This is due to rewetting 80% of today's agricultural peatlands and using the other 20% predominantly as shallow-drained grassland.
3. Emissions from agriculturally used mineral soils decrease by approximately 39% due to low emission fertilisation strategies (reduced nitrogen surpluses and increased nitrogen use efficiency).

In addition to these emissions reductions, there are other climate benefits related to the scenario, including further emissions reductions and carbon removals. The additional gains listed below are based on rough estimates.

Additional estimated contributions to **emissions reductions**:

- By 2045, some 64 million tonnes of renewable carbon are supplied through woody biomass produced on agricultural land. This biomass is used to substitute fossil feedstock for energy and material use. Applying a rather conservative substitution factor of 0.55, at least 131 $MtCO_2$ emissions could be mitigated annually by utilising wood from fast-growing trees when these are fully established in 2045.
- Emissions related to energy consumption in agriculture and forestry totalled nearly 74 $MtCO_2eq$ in 2020. These emissions can be partially avoided by electrifying stationary energy use and vehicles operating for short intervals and sourcing the electricity from renewable energy. In contrast, off-road vehicles performing heavy-duty work will likely continue to require energy-dense liquid fuels in the future. Consequently, some combustion engines may still run on biofuels.

Reduction of greenhouse gas emissions from EU agriculture and agricultural peatlands between 2020 and 2045* → Fig. B



Agora Agriculture based on CAPRI results. * N_2O emissions from manure application under "livestock and manure", N_2O emissions from organic soils under "agricultural peatlands"; ** estimate for emissions from agricultural peatlands with CAPRI data on organic soils and emission factors from IPCC (2014), see Annex Chapter 7

- Agricultural land is used for energy production through wind and solar PV. We project an installed capacity of 711 GW of ground-mounted solar PV, representing an additional capacity of 612 GW in 2045 compared to the current capacity. Based on today's energy mix, this additional installed capacity of solar PV is estimated to save 127 $MtCO_2$ per year. However, these savings will decrease as the share of renewable electricity increases.

Estimated contribution to **carbon removals**:

- Forest net carbon removals in 2045 are estimated to be around 290 $MtCO_2eq$, similar to 2020 levels. The level of removals, however, depends on the effects of climate change on forests, adaptation efforts and forest management strategies that support the forest sink.
- Annual carbon removals by harvested wood products are projected to increase by 17 $MtCO_2$ compared to today, reaching approximately 58 $MtCO_2$ in 2045. This is due to the growing use of woody biomass for materials.
- Carbon removals on arable land are achieved through permanent land-use changes. In our scenario, planting hedgerows on 0.6 million hectares between 2025 and 2045 is expected to sequester approximately 112 $MtCO_2$ over this period, or around 5 $MtCO_2$ annually on average.
- Additionally, establishing around 13 million hectares of fast-growing trees on agricultural land is

projected to achieve negative emissions of about 650 $MtCO_2$ between 2025 and 2045, or around 30 $MtCO_2$ per year on average.

Biodiversity

While we quantify the contribution of our scenario to climate change mitigation, we do not quantify its effects on biodiversity. The measures implemented for conserving and enhancing biodiversity, however, as well as our assumptions about their spatial and temporal scales, are based on meta-studies that examine the relationship between land use and biodiversity.

It is important to enhance biodiversity within the EU while also reducing pressure on land resources globally. Lowering yields in the EU leads to higher imports or lower exports if domestic demand remains unchanged. The major challenge, therefore, is to find a balance between maintaining high land productivity and providing species-rich habitats.

Protecting biodiversity requires a landscape perspective. Our proposed measures encompass the provision of semi-natural habitats, structurally diverse cropping systems, integrated plant protection and low-emission fertilisation. This includes diverse, site-adapted crop rotations and that the average field size at the landscape level is smaller than 6 hectares. Additionally, we assume cutting the use of plant protection products by half and reducing their associated risks, as well as a 50% reduction in nitrogen balance surpluses by 2045 compared to 2020 levels.

Instead of imposing fixed set-aside obligations for each farm, we assume that 20% semi-natural landscape features[1] are achieved at the landscape level. When calculating the regional land required for semi-natural habitats, we consider existing landscape features both on and adjacent to agricultural land. This includes semi-intensive grassland management and the integration of fast-growing trees into the agricultural landscape. Consequently, additional semi-natural features on arable land are only necessary in landscapes where the 20% target is not met. According to our analysis, an average of around 5% of arable land in the EU needs to be dedicated to semi-natural features by 2045, though this varies significantly by region.

Maintaining permanent grasslands is another crucial factor for enhancing biodiversity in agricultural landscapes. Similarly, forest biodiversity can be improved through management practices such as a modest reduction in harvest levels, the implementation of forest adaptation strategies and through afforestation.

Health and social well-being

Our study shows that the combination of efficient land use and sustainable consumption can contribute to food security both within the EU and globally. In our scenario, sufficient food is available in the EU to support nutritionally healthy diets, with self-sufficiency rates for most relevant food products either remaining stable or increasing by mid-century. The implemented land use measures contribute to a long-term resilient food system and ecological stability. Moreover, fair food environments enhance the availability, affordability and appeal of foods for healthier and more sustainable consumption, meeting nutritional needs and reducing diet-related diseases. Social policy measures further enhance access to healthy diets for socio-economically vulnerable consumers.

The EU can also improve its contribution to global food security by alleviating pressure on global land resources. By 2045, the EU shifts from being a net importer of virtual land in 2020 to becoming a substantial net exporter. This development is largely driven by a reduction in feed imports and an increase in net exports of dairy products. Most other trade balances remain relatively stable between 2020 and 2045.

1 The term "semi-natural landscape features" encompasses both non-crop habitats (e.g., hedges, flowering strips, fallow land, ditches and ponds) and crop habitats that are farmed within the boundaries of biodiversity conservation (e.g., perennial legume-grass mixtures, extensively grazed or mown permanent grassland and agroforestry systems).

Achieving this shift in virtual land trade requires changes in food consumption patterns. We conducted a sensitivity analysis which shows that applying our scenario with all the planned changes in agriculture and forestry but maintaining 2020 consumption patterns and not reducing food waste, the EU would significantly increase its net import of virtual land by 2045.

Animal welfare

Another element of the scenario is the enhancement of animal welfare through improved husbandry and management practices for cattle, pigs and poultry. This includes providing more space, species-specific environments, outdoor access and greater opportunities for animals to express natural behaviours. Common practices include outdoor runs, free-range housing and enrichments such as straw. Non-curative procedures like tail docking in pigs and beak trimming in poultry are mostly eliminated. The use of cages for poultry has been phased out. For cattle and other ruminants, a larger proportion of animals now have access to pasture. To support the implementation and economic viability of these improvements in an environment of international competition, increased animal welfare must be rewarded through public payments.

Economic opportunities for the land use sectors and rural areas

Our scenario implies challenges but also a range of economic opportunities for agriculture and forestry. It involves substantial changes in consumption and production, with considerable implications for some existing business models. At the same time, opportunities may arise from the growing demand for products and the provision of public goods by agriculture and forestry. By rewarding the provision of public goods through public or private funding, these goods could be integrated into business models and contribute to the income of farmers and forest owners.

We estimate the cost of providing certain public goods and the potential value of carbon removals associated with some of these services. While both of these calculations are rough approximations, they offer an indication of the potential for developing business models around the delivery of public goods by farmers and forest owners:

- Providing higher levels of animal welfare across the EU may result in additional annual production costs of about 10–20 billion euro. Public payments to remunerate for these higher welfare standards can be particularly important for farmers adversely affected by the overall decline in livestock production.
- Creating and managing biodiverse agricultural landscapes would result in investment costs, as well as annual costs incurred and income foregone for: 1) establishing semi-natural landscape features, 2) diversifying crop rotations, 3) managing smaller cropping units and 4) reducing the intensity of grassland use. We estimate these costs at about 90 billion euro in investments from 2025 to 2045, with annual costs ranging from 9 to 20 billion euro.
- Rewetting drained agricultural peatlands reduces greenhouse gas emissions effectively, but it comes with opportunity and investment costs for farmers. We estimate short-term opportunity costs of up to 1 billion euro annually and about 12 billion euro in total for the period between 2025 and 2045.
- We anticipate that approximately half of the afforestation in our scenario will require active efforts, involving necessary investments estimated at 2–3 billion euro annually between 2025 and 2045. Forest adaptation measures are projected to cost about 12 billion euro annually during the same period. Both measures support critical forest ecosystem services, including biodiversity protection and carbon removals.

As the EU economy transitions to climate neutrality, these carbon removal measures will generate societal value, which can be estimated based on future carbon prices. Predicting future carbon prices is difficult, with current estimates ranging from under 100 to well over 200 euro per tonne of CO_2 by mid-century. We use a conservative carbon price estimate of 100 euro per tonne of CO_2

to provide a rough assessment of the value of the anticipated carbon removals:

- The introduction of hedges and fast-growing trees on agricultural land is projected to generate negative emissions of 35 $MtCO_2$ annually on average for the period from 2025 to 2045. Based on a future carbon price of 100 euro per tonne, this could create a societal value of 3.5 billion euro annually.
- Harvest reduction and afforestation could achieve an average of 50 $MtCO_2$ in negative emissions annually for the period up to 2045. At a carbon price of 100 euro per tonne, this equates to a societal value of around 5 billion euro annually.
- Finally, harvested wood products would generate an additional 17 $MtCO_2$ in negative emissions, yielding a societal value of about 1.7 billion euro annually at a carbon price of 100 euro per tonne.

EU policy options

The 2024–2029 EU legislative period will be critical for strengthening the ability of farmers, forest owners, rural communities and consumers to actively contribute to societally agreed sustainability objectives. Policymakers must demonstrate long-term commitment and take decisive actions to create enabling policy environments. We emphasise three key considerations in designing an effective policy mix:

- **Use of market-based instruments**: Instead of relying primarily on command-and-control regulation, market-based instruments are important policy options. Such instruments can include an EU-wide emissions trading system for greenhouse gas emissions from agriculture and agricultural peatlands, as well as tradable certificates or taxes for plant protection products. By utilising price signals and economic incentives, such policy measures offer greater flexibility for economic actors to identify suitable management solutions, thereby safeguarding entrepreneurial options.
- **Payments for public goods**: Public payments to support the provision of public goods are a critical component in developing more sustainable business models in the land use sectors.
- **Fair food environments for consumers**: Consumers need enabling conditions. The wide range of sustainability benefits of our scenario largely relies on a shift to more plant-rich diets and on reduced food waste. Fair food environments are essential for making healthier and more sustainable food choices easier and more affordable for consumers.

The creation of an enabling policy environment requires a broad policy mix. We offer a detailed discussion of policy options for each of the six thematic areas in Chapter 4 of our study. In addition, we describe five cross-cutting policy priorities for the land use sectors, food system and bioeconomy for the 2024–2029 EU legislative period and beyond:

1. A climate policy for the land use sectors
2. A Common Agricultural Policy for public goods
3. An EU legislative framework to promote sustainable food systems
4. An action plan for the efficient use of biomass in the bioeconomy
5. A European Rural Deal

1. A climate policy for the land use sectors

The design of a post-2030 climate framework will be one of the most consequential political processes of the 2024–2029 EU legislative period. Four aspects are particularly relevant for shaping a climate governance framework for agriculture and forestry:

A) **Defining an appropriate level of ambition for the contribution of the land use sectors to climate neutrality.** In our scenario, greenhouse gas emissions from agriculture and agricultural peatlands decline by about 60%, resulting in around 186 $MtCO_2eq$ of residual emissions by 2045. Considerable uncertainties surround potential land-based carbon removals. We estimate that net removals from forests could reach 290 $MtCO_2eq$ in 2045, which we view as an optimistic projection. Additionally, we assume 58 $MtCO_2$ removals from harvested wood products by the same year. Carbon removals from the planting of hedges and fast-growing trees on agricultural land are

A policy mix for the land use sectors, food demand and biomass in the bioeconomy

→ Fig. C

Cross-cutting policy priorities

- Climate policy for the land use sectors
- A Common Agricultural Policy for public goods
- EU legislative framework to promote sustainable food systems
- Action plan for the efficient use of biomass in the bioeconomy
- A European Rural Deal

Selected policies contributing to the scenario

Food demand	Food waste reduction policies, including binding targets
	Create fair food environments through an integrated mix of EU and national policies
Arable farming	Standalone Biodiversity Index
	Strengthen coordination at landscape level and innovation partnerships
	A Common Agricultural Data Space
	Price nitrogen surplus and the risk of plant protection products
Livestock farming	Policy mix to reduce livestock emissions including pricing emissions
	Improve animal welfare through standards, payments and labelling
	Support for pasture-based systems and economic alternatives
Agricultural peatlands	Price emissions from peatlands
	Long-term financial incentives for peatland rewetting
	Support the creation of new value chains for paludiculture and lignocellulosic biomass
Biomass	Support the cultivation of lignocellulosic crops
	Efficiently utilising biomass to defossilise the economy
	Align incentives to prioritise the material use of biomass
Forest management	Stimulate carbon removals in forests
	Incentives for adaptative forest management and afforestation

Agora Agriculture

estimated to average 35 $MtCO_2$ annually between 2025 and 2045. These estimates offer a solid foundation for discussions on the level of ambition required for the land use sectors in climate change mitigation and for establishing climate targets.

B) **Translating climate ambition into climate targets.** Establishing a set of binding targets is a precondition for a long-term, predictable climate policy. We consider that:
   - Introducing an EU-wide reduction target for the combined greenhouse gas emissions from agriculture and agricultural peatlands would incentivise the sector to contribute more effectively to overall emissions reductions.
   - Establishing a separate target for carbon removals would complement an EU-wide net emissions reduction target. It is also important to consider setting separate sub-targets for land-based and technological removals. Additionally, a specific net removals target for forests would highlight the critical role forests play in carbon removals.

C) **Designing a framework to govern emissions from agriculture and agricultural peatlands.** The option of implementing an EU-wide Emissions Trading System (ETS) for agriculture-related greenhouse gas emissions is a subject of intense debate Despite the complexities of establishing an ETS for the agri-food sector, such a system would reduce transaction costs and uncertainties compared to using multiple policy instruments for managing emissions. To be effective, an ETS should cover the major sources of emissions related to the agricultural sector. This includes methane emissions from livestock, nitrous oxide emissions from agricultural soils and emissions from agricultural peatlands. In some cases, allowances might be allocated for free (grandfathered), such as for emissions from peatlands.

D) **Introducing credible incentives for land-based carbon removals.** Carbon removals are indispensable for achieving climate neutrality by counterbalancing residual emissions. In the coming years, when removals are not yet needed for compensating hard-to-abate residual emissions, EU policies would need to focus on creating income opportunities through land-based removals. This should be done without compromising the ambition of emissions reduction efforts.

2. A Common Agricultural Policy for public goods

The Common Agricultural Policy (CAP) is the primary European funding mechanism for the agricultural sector, accounting for over 30% of the total EU budget (European Commission 2024c).

In principle, the current CAP permits member states to use all available funds to reward the provision of public goods by agriculture. However, member states also have significant flexibility not to do so. As a result, the CAP budget is not sufficiently targeted at providing public goods. To improve the environmental and socio-economic impact of the CAP, the following steps can be taken.

A) **Gradually phase out basic and coupled income support.** This will allow farmers, markets and administrations time to adapt.

B) **Redirect CAP funds to enhance their environmental and socio-economic impact.**

C) **Simplify and increase the flexibility of the CAP:** Merge the budget of the two pillars into a single fund; introduce options for multi-year and single-year measures; replace conditionality with more flexible approaches that maintain baseline environmental protection without imposing excessive additional requirements on the sector without corresponding remuneration.

3. An EU legislative framework to promote sustainable food systems

Shifting food consumption patterns is essential for public health and for achieving broader sustainability objectives, such as reducing greenhouse gas emissions and protecting biodiversity. However, integrated food policies that offer coherent solutions across health, social, economic, environmental, climate and agricultural policy domains are yet to be developed at both the EU and national levels.

In 2020, the European Commission announced its intention to propose a legislative framework to facilitate the transition towards a more sustainable EU food system. This proposal has not yet been published. Putting forward a legislative framework to negotiate and establish a coherent policy approach for enhancing sustainability across the food chain needs to be a central task for the 2024–2029 EU legislative period.

We consider the following two elements to be important for such a framework:

A) Establishing objectives and principles to guide policy development and support predictability at both the EU and national levels.
B) Introducing a mechanism to initiate the development of national food strategies and action plans.

4. An action plan for the efficient use of biomass in the bioeconomy

The EU's current policy framework lacks coherent, long-term incentives to stimulate a bioeconomy that efficiently utilises biomass. Conflicting policy signals undermine the planning security needed to stimulate future-oriented investments in the bioeconomy. For example, the policy incentives for bioenergy often conflict with the most climate- and land-efficient uses of biomass.

The review of the Bioeconomy Strategy planned by the European Commission in 2025 presents an opportunity to address these issues. To support the development of a sustainable bioeconomy and create synergies between policy fields affecting biomass supply and use, this revision could include an action plan for the efficient use of biomass in the bioeconomy, including measures for carbon removal.

An action plan for biomass would establish strategic priorities for the coming months and years. It could address areas where current evidence shows a need for policy adjustments to reduce existing distortions and enhance system-wide benefits. Additionally, it can also include areas requiring further analysis regarding trade-offs, benefits and the technological and economic potential of different biomass uses. Key priorities for such an action plan may include:

A) **Adopt a policy road map to stimulate long-lasting and circular uses of biomass**.
B) **Incentivise the development of new value chains in the bioeconomy**, particularly for long-lasting products from paludiculture and forestry, for biogas production using sustainable feedstocks and for carbon removals.
C) **Promote a larger role for fast-growing trees in biomass production.** When well-integrated into the landscape, fast-growing trees offer significant benefits across multiple sustainability dimensions, including carbon sequestration, biodiversity, water protection and climate adaptation.
D) **Evaluate the international trade implications of EU biomass supply and demand** to determine necessary safeguards, such as carbon border adjustments, to prevent carbon leakage and address the offshoring of negative environmental and social impacts associated with EU biomass systems.
E) **Provide a comprehensive analysis of the current biomass production, extraction and usage as well as their future potential** to contribute to different societal objectives.

5. A European Rural Deal

Securing a reliable funding mix is critical for translating the potential opportunities from the transition towards climate neutrality into tangible outcomes for economic actors. The upcoming negotiations on the Multiannual Financial Framework (MFF) present a possibility to address this need, as they will determine the size and priorities of the EU budget for the 2028–2034 period. For this process, it is essential to engage in a well-informed debate about the costs associated with necessary changes in the land use sectors. This discussion should address the equitable distribution of these costs, the roles of various funding sources and the responsibilities at the EU, national and local levels.

While evaluating funding needs, it is important to recognise that the economic potential of the land use sectors is closely tied to the rural contexts in which they operate. Much of EU's economic development is anticipated to be driven by the ongoing "green and digital" transitions. While these can create opportunities, they also risk exacerbating disparities between some rural and urban areas.

Despite various EU rural development initiatives launched over the years, the challenges faced by rural areas may not have been addressed with the necessary scale and urgency. Introducing a "European Rural Deal" as a flagship political project for the 2024–2029 EU legislative period could contribute to a long-term economic transformation. It may include measures to improve social cohesion and ensure that rural communities can sufficiently contribute to and benefit from a climate neutral society. A European Rural Deal could:

A) **Create future-oriented economic opportunities in rural areas** to enable innovative business models that generate income and advance climate neutrality,
B) **Support the development of infrastructure for the benefit of rural communities**, including high-capacity digital networks, clean mobility systems and renewable energy,
C) **Maintain and enhance the attractiveness of rural living environments** by facilitating access to social services, including education, healthcare and cultural amenities.

The overarching objective of a European Rural Deal would be to ensure that the transition towards climate neutrality becomes an opportunity for rural areas across the EU.

1 Introduction

With this study, we present a scenario for agriculture and forestry – the land use sectors – in a climate neutral EU by the middle of this century. Our scenario shows that the land use sectors, as part of the food system and the bioeconomy, can contribute substantially to climate neutrality, support healthier and more sustainable food consumption, enhance biodiversity in agricultural landscapes and forests, and produce biomass to help replace fossil carbon used throughout the economy. At the same time, animal welfare improves, and the EU becomes a net exporter of virtual agricultural land, thereby reducing the pressure on global land resources and indirectly contributing to food security.

Realising such a scenario is challenging – but it is possible if land is used efficiently, and if the demand for food, feed and other biomass is more sustainable than today. This requires an enabling policy environment which provides economic opportunities for farmers, forest owners and rural entrepreneurs, as well as fair food environments for consumers.

In this study, we describe how, in the context of changes in demand for food, feed and other biomass, the land use sectors can contribute to core sustainability objectives agreed by societies throughout the EU. In doing so, we aim to support a constructive debate about the future of agriculture and forestry, both during the 2024–2029 EU legislative cycle and beyond. We also hope this study encourages finding common ground for political agreements about the policies required to enable economic actors in the food and land use sectors, as well as consumers, to respond to current sustainability challenges.

During the previous legislative period, the European Green Deal and its accompanying Farm to Fork Strategy presented a comprehensive set of objectives and a package of measures to advance climate, environmental, health and consumer protection as well as animal welfare goals. But many of the initiatives affecting the food and land use sectors envisioned in this package were strongly contested. While aspiring to address existing environmental and social challenges, the European Green Deal may have fallen short in offering enough opportunities for land users and rural entrepreneurs.

The absence of a broadly shared vision among EU stakeholders about a viable future for the land use sectors that also delivers on sustainability objectives has hindered the development of practical solutions and has come at a price. We observe farmers and forest owners raising concerns about a lack of long-term planning security and the limited recognition of their societal and entrepreneurial roles. Environmental stakeholders, at the same time, see little progress on some of the fundamental sustainability dimensions affected by agriculture and forestry, including their impacts on climate change, biodiversity, other environmental concerns, as well as animal welfare.

Meanwhile, agriculture and forestry will be gaining further relevance as the demand for their products and services is expected to increase. If the policy environment provides the right incentives, the growing demand for biomass from the bioeconomy, for renewable energies, and payments for public goods will support new business models for these sectors. At the same time, this will contribute to building more sustainable and resilient societies.

We consider this EU legislative period to be crucial both for delivering policy solutions for the land use sectors and for building confidence among stakeholders. First, confidence that there is a viable future for the land use sectors as part of a sustainable food system and bioeconomy. Second, confidence in the capacity of public institutions, both EU and national, to support the land use sectors achieve this aim. Some of the changes involved in realising the potential to deliver on sustainability objectives will be demanding. Policymakers will need to strengthen the ability of farmers, forest owners, rural entrepreneurs and consumers to actively contribute to sustainability objectives with a long-term commitment and an integrated policy mix.

A consensus among key stakeholders on the cornerstones of a vision for the future of agriculture, forestry, the food system and the bioeconomy would encourage policymakers to make steps towards a coherent, comprehensive and long-term policy agenda. The Strategic Dialogue on the Future of EU Agriculture was announced by the President of the European Commission in 2023 with the aim to create a space for building such consensus (European Commission 2023n). The outcomes of this initiative indicate there is much to gain from working together towards a shared and agreed perspective. This can facilitate the development of long-term policy pathways beyond the relatively short legislative periods and provide an operating space for policymakers that transcends party-political lines. However, setting up such a stakeholder dialogue comes with political responsibility. Once a consensus is on the table, it is important that policymakers make use of it.

Working on consolidating, further elaborating and implementing a broad consensus becomes even more important in the current challenging political context. Russia's war against Ukraine is still ongoing. Geopolitical competition with other parts of the world has intensified. Defence and security are high on the agenda. The EU is, moreover, on the cusp of enlargement. Negotiations on the membership of Ukraine and five countries in the Western Balkans are underway. These and other priorities put new funding demands on the EU budget, which are likely to compete with other societal needs, requiring an effective management of public resources. These pressures risk further polarisation and short-term thinking.

Concerns about food security are high on the EU's agenda. Ensuring food security is often seen as incompatible with making further steps towards sustainability. Our scenario shows that there is no intrinsic contradiction between maintaining food security in the EU, contributing to global food security, and making progress on environmental objectives. Rather, supporting food security, providing economic opportunities, and contributing to climate neutrality and biodiversity protection can go together.

With our scenario we aim to show a future that could, in principle, be realisable and support the diverse objectives our societies are committed to achieving. Above all, we hope this scenario contributes to a serious debate about the future of the land use sectors and helps create a space for solutions-oriented negotiations, based in evidence and respecting the complexities involved.

This is the first study by Agora Agriculture. We will be building on it in the years ahead, deepening and developing the questions and proposals raised in this study, as well as filling the gaps.

The study is structured as follows:

- **Chapter 2** outlines the scope of the study, key terms and concepts and the methodology used.
- **Chapter 3** describes the main sustainability objectives relevant to this study that EU societies have committed themselves to achieving. These are climate neutrality, biodiversity protection, health and social well-being, animal welfare and economic viability. The chapter further highlights how the land use sectors and food demand currently relate to these objectives, as well as the EU policy context governing their achievement.
- **Chapter 4** describes how, in our scenario, agriculture and forestry can contribute to a climate neutral EU in the context of changes in demand for food, feed and other biomass. We provide detailed findings on the main thematic areas of this study, namely biomass for the bioeconomy, food demand, livestock farming, arable farming, agricultural peatlands and forests. Each thematic section includes both a scenario description and policy options.
- **Chapter 5** discusses the guiding considerations underlying the policy mix proposed in Chapter 4. It also develops five cross-cutting policy initiatives that could act as building blocks for European policy priorities for the EU's 2024–2029 legislative period and beyond.
- The **Annex** to the study provides details about the data used, the additional calculations supporting the study and the quantitative model. It is published in a separate document and is referred to throughout the study.

2 Methods and key concepts

This chapter serves as a brief guide to reading our study. It outlines the scope of the study, the methodology used, defines key terms and concepts and highlights the added value the study brings. It also acknowledges some of the themes that we have not addressed in depth, despite their relevance.

Scenario

In this study, we put forward one scenario for the future of EU agriculture and forestry in the context of the food system and the bioeconomy. Our analysis covers agriculture, forestry, food consumption and biomass demand for energy and material use. The scenario offers an integrated vision, taking into account the interactions between the land use sectors, the food system and the bioeconomy as part of a global market for agricultural and forestry products.

We describe one plausible future for the land use sectors among a variety of possible futures. Although many other options are conceivable, we demonstrate the central importance of certain measures to simultaneously achieve results for a range of sustainability objectives. For example, we conduct a sensitivity analysis showing the relevance of food consumption changes and food waste reduction for achieving a significant contribution to sustainability objectives in the EU without increasing reliance on food imports (Chapter 4.1).

The conditions we set in the scenario apply equally to all EU farm types and agricultural production systems. No distinction is made between conventional and organic farming. In organic farming some of the scenario's conditions are easier to implement or are already implemented, others are not. The conversion to organic farming is neither a necessary nor sufficient condition for the agricultural sector's transition towards more sustainability. However, organic farming is a valuable driver of innovations in agriculture, as it contributes to the diversity and competition of ideas for production systems.

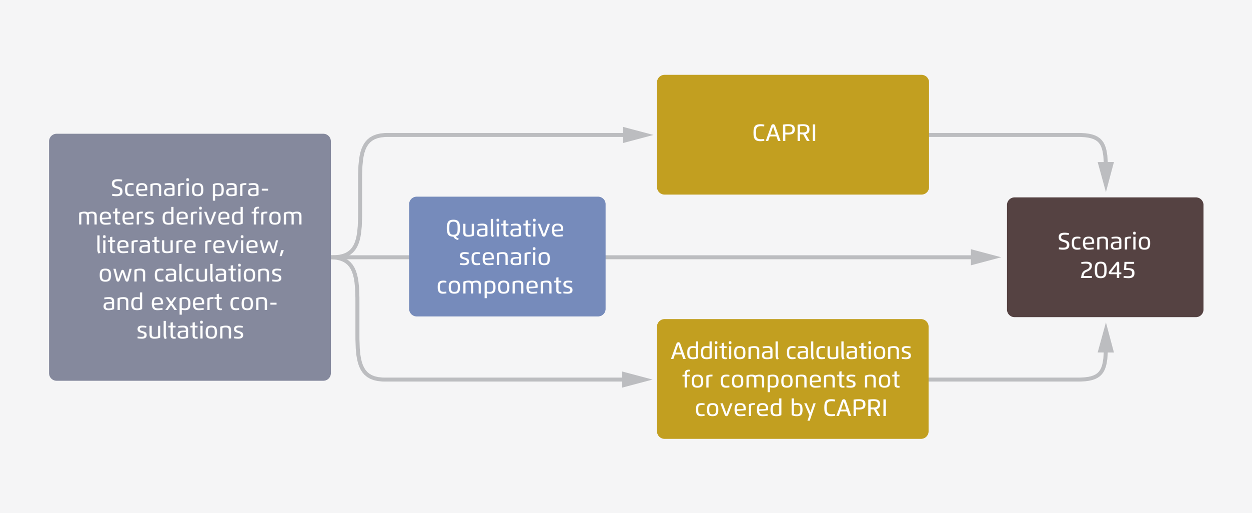
We take 2045 as the target date for our scenario, as we align the study with Germany's legal commitment to become climate neutral by 2045. The EU legal target for climate neutrality is set for 2050. We consider the results of the scenario for 2045 to also be applicable to 2050, permitting an extra five years for implementation. The assumptions in the scenario for the EU are based on its current composition of 27 member states. By 2045/2050, the EU may have a different composition.

Methodology

The outcomes presented in this study result from four analytical steps (Figure 1):

1. We describe the current state of the land use sectors and food system, as well as the relevant EU policy context, in relation to societally agreed sustainability objectives, including climate, biodiversity, health and social well-being, animal welfare and economic viability (Chapter 3). This analysis is based on a literature review and expert consultations.
2. We identify the most important levers to contribute to these sustainability objectives for biomass in the bioeconomy, food demand, livestock farming, arable farming, agricultural peatlands and forests (Chapter 4). This analysis is also based on a iterature review and expert consultations.
3. We sketch a scenario for climate neutrality, in which EU agriculture and forestry – in the context of changes in the demand for food, feed and other biomass – make a significant contribution to societally agreed sustainability objectives (Chapter 4). This scenario is based largely on quantitative analyses:
   - For agricultural production and food demand, our quantitative analysis relies primarily on a global partial equilibrium model of the agricultural

Study methodology → Fig. 1



Agora Agriculture

sector, the Common Agricultural Policy Regionalised Impact (CAPRI) Modelling System. The model analysis was conducted by a team of external researchers in close exchange with the Agora Agriculture team, the latter being responsible for scenario design. It serves to translate our set of assumptions into a technically consistent agricultural production and demand pattern by 2045. The depiction of production, consumption and trade of agricultural products in CAPRI as well as environmental impacts of agriculture allows us to derive quantified economic and environmental results.

- The CAPRI model is an established economic model for analysing the development of the EU agricultural sector. Its supply module includes 215 NUTS-2 regions[2] within the EU-27. Environmental targets can be implemented through a set of input variables, while still allowing flexibility in production responses. Data for the base year is derived mainly from Eurostat and other official statistics (Annex Chapter 1).
- The production of biomass for energy and material uses on agricultural land in 2045 is based on exogeneous projections of future demand.
- Forestry is not depicted in CAPRI. The biomass supply from forests is derived from 2020 levels, to which we apply a moderate reduction. Changes in the forest area are derived from past trends, and the effects on agricultural land are integrated into the CAPRI model (Annex Chapter 8).
- Changes assumed for forest management, adaptation and afforestation are not modelled but based on additional calculations outside of CAPRI.

4. For each thematic focus, we outline and analyse a comprehensive, but not exhaustive, set of policy instruments that we expect to support our scenario (Chapter 4). On the same basis, we also propose five European policy priorities for the 2024–2029 EU legislative period (Chapter 5). These suggestions are based on a literature review and expert consultations.

Key terms and concepts

The terms and concepts used in our study are defined in the chapters where they are introduced. Some of the key concepts that recur throughout the study are introduced here:

— In our study, the term **land use sectors** refers to the economic sectors of agriculture and forestry. It does not cover other land uses such as settlements or wetlands. The way we use the term land use sectors does not refer to the definition of the

2 NUTS = Nomenclature of territorial units for statistics.

land use sectors in the climate reporting category of Land Use, Land-Use Change and Forestry (LULUCF), which reports both greenhouse gas emissions and carbon removals from all land uses (Regulation (EU) 2018/841).

– We often refer to the combined **greenhouse gas emissions from agriculture and agricultural peatlands.** This means combining emissions from the climate reporting category of agriculture, with the carbon dioxide (CO_2) and methane (CH_4) emissions from agriculturally used organic soils (agricultural peatlands), which are reported under the LULUCF category.[3] Agricultural peatlands are an integral part of the agricultural holding and farm management decisions, which is why we consider these emissions together with those from agriculture. We apply a customised calculation to estimate the emissions from agricultural peatlands (Chapter 4.6 and Annex Chapter 7).
– **Carbon dioxide removals** (carbon removals) are defined as "anthropogenic activities removing CO_2 from the atmosphere and durably storing it in geological, terrestrial, or ocean reservoirs, or in products" (IPCC 2018: 24). Carbon removals, also called "negative emissions", span a range of practices, technologies and approaches that deliberately remove carbon dioxide from the atmosphere. In this study, we refer to "land-based removals" to denote removals in soils and biomass, including in forests and wood products, such as in construction materials. We refer to "technological removals" to denote removals achieved through methods like biochar, Biogenic Carbon Capture and Storage (BioCCS) and Direct Air Carbon Capture and Storage (DACCS).
– The **bioeconomy** is a comprehensive concept covering the use of biological resources from land and sea, such as crops, forests, animals and micro-organisms, to produce food, materials and energy (European Commission 2018a). The increasing demand for biomass is a key driver of land-use change in our scenario. We distinguish between biomass uses for food, feed, energy and materials, which includes uses such as wood for construction, as well as biomass used as a feedstock in the chemical industry for producing bioplastics and other biochemicals.
– The **food system** covers "the entire range of actors and their interlinked value-adding activities involved in the production, aggregation, processing, distribution, consumption and disposal of food products that originate from agriculture, forestry or fisheries, and parts of the broader economic, societal and natural environments in which they are embedded" (FAO 2018: 1). In this study the focus is on the land-based food system. Fisheries and aquaculture are not considered and are addressed only within the consideration of consumption patterns.
– The **food environment** is an analytical concept, which is defined as "the physical, economic, political and socio-cultural context in which consumers engage with the food system to make their decisions about acquiring, preparing and consuming food" (HLPE 2017: 28). It supports understanding the emergence of food consumption patterns and how demand shifts can be enabled through actions along the food chain, thereby contributing to more sustainable food systems.
– We emphasise throughout the study the importance of **efficient land use.** We use the term in the sense of making the most of the multiple benefits associated with land. It refers to deploying land wisely to contribute to the multiple outputs of land-based production systems, including food, feed, biomass for materials, energy, biodiversity and carbon stocks in nature-based systems. Land use can become more efficient through the interplay between an efficient allocation of land and efficient land management practices. An efficient use of land contributes to reducing the pressure on scarce land resources within and outside the EU.
– We use the term **sustainability** in different contexts in this study. According to the most widely accepted definition, sustainability refers to a process of change, rather than a specific societal outcome (WBAE 2020). Sustainable development is described as a "development that meets the needs of the present without compromising the

3 Nitrous oxide (N_2O) emissions from agricultural peatlands are reported under the category of agriculture.

ability of future generations to meet their own needs" (Brundtland et al. 1987: 41). To operationalise sustainability for this study, we rely on the five objectives mentioned above, namely climate neutrality, biodiversity protection, human health and social well-being, animal welfare and economic viability. These objectives have been agreed upon by societies across the EU to make the ongoing process of societal change more sustainable in terms of ecological, economic and social dimensions. In the study, we refer to systems or practices as more sustainable when there is scientific evidence that they contribute to the achievement of societally agreed sustainability objectives, acknowledging trade-offs among these objectives.
- **Public goods** refer to a range of goods and services of societal interest, for which the market mechanism does not work well and which are therefore usually undersupplied by the market (European Commission et al. 2010, OECD 2013, Westhoek et al. 2013). Many public goods overlap with, or contribute to, the sustainability dimensions referred to above. Incentivising the provision of public goods by economic actors in the land use sectors has the potential to both support more sustainable business models and contribute to environmental, health and ethical objectives simultaneously. A further discussion on public goods is included in Chapter 5.2.

We aim to comprehensively address the land use sectors, food demand and biomass demand for the bioeconomy. Below we highlight some aspects we have not covered in depth:

- The **impacts of climate change** on agriculture and forestry are not analysed in depth. While agricultural yield projections in the CAPRI model reflect some effects of climate change, the frequency, scope and impact of extreme weather events are difficult to predict and are not considered in our scenario.
- The importance of **climate adaptation** is discussed throughout the study (Chapters 4.2–4.5, 4.7 and 5.5), but we do not develop a comprehensive perspective on climate adaptation needs and policies.
- **Social aspects and impacts on employment** are addressed only to a limited extent, although they are important for ensuring the social and economic viability of a more sustainable agricultural and food system. Likewise, we do not analyse how our scenario may affect structural change in the agricultural sector.
- We do not analyse the impact of **future food prices** on the agricultural sector and consumers since these will be determined predominantly by global price developments.
- While we reflect on the role of **food supply chains**, we do not address in detail the economic challenges and opportunities along these chains. We have also not analysed in depth the role of **food industries**, including food manufacturers, retailers and food service industries, in the transition towards a more sustainable food system.
- We neither comprehensively assess the economic potential nor the investment needs for the development of **new value chains**, including in the bioeconomy, for protein diversification, or the expansion of fruits and vegetable production.
- Public funds for rewarding the provision of public goods are necessary for creating opportunities in the land use sectors and rural economies from a transition to greater sustainability. While we address public funding instruments throughout various parts of the study, as well as some private funding mechanisms, we do not elaborate in detail on the potential role of **sustainable finance** as an instrument in the funding mix.

3 The EU land use sectors and food system in the context of societal objectives

Agriculture and forestry are relatively small sectors of the European economy in terms of Gross Domestic Product (GDP) and employment. Their societal relevance, however, is large. Covering nearly 75% of the EU's land surface (Eurostat 2021), they produce food and raw materials, and shape critical ecosystems. As integral parts of the food system and bioeconomy, and historically connected to the cultural development of rural areas and landscapes, agriculture and forestry play a special role in European societies.

EU member states have committed themselves to sustainability objectives, both as part of the EU and in other contexts. Such objectives range from becoming climate neutral in 2050 to protecting natural habitats and advancing the social and economic well-being of the population. The impacts of agriculture, forestry and the wider food system on different sustainability dimensions have been widely analysed in the academic literature (European Commission & Group of Chief Scientific Advisors 2020, Leip et al. 2015, Springmann et al. 2018, Swinburn et al. 2019). In this chapter, the aim is not to provide a comprehensive reflection of this discussion. Instead, it briefly highlights how the food system and land use sectors relate to those sustainability objectives most relevant to the scope of this study. It also touches on the economic and policy contexts that shape the sectors' opportunities and constraints.

Below, we describe five sustainability objectives central to this study: climate neutrality (3.1), biodiversity protection (3.2), human health and well-being (3.3), animal welfare (3.4) and economic viability (3.5).

3.1 Climate neutrality

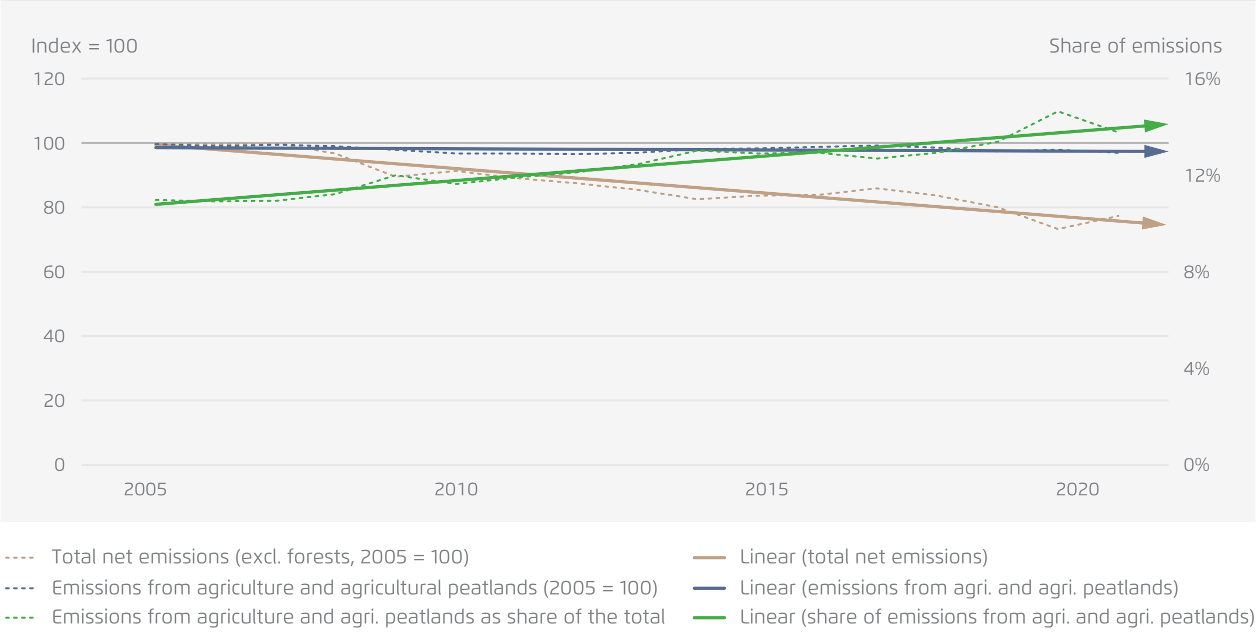
Mitigating climate change is a major global challenge. The Paris Agreement, ratified by the EU and all its member states, commits parties to keep the increase in global average temperatures to "well below" 2 °C and make efforts to limit warming to 1.5 °C above pre-industrial levels (UNFCCC 2015). The European Climate Law (Regulation (EU) 2021/1119) sets a binding target to achieve climate neutrality in the EU by 2050 and was introduced as part of the European Green Deal (European Commission 2019b). Finland, Germany and Sweden have introduced binding national climate neutrality targets even before 2050.

The land use sectors both emit greenhouse gases and remove carbon from the atmosphere. This makes them uniquely positioned to contribute to climate change mitigation. Emissions from agriculture and agricultural peatlands accounted for approximately 14% of total EU greenhouse gas emissions in 2020 (EEA 2024c). Despite a significant reduction in agricultural emissions between 1990 and 2005 of approximately 20%, reductions have largely stalled since then, with only a 2% decline between 2005 and 2020 (EEA 2022c). Based on current estimates, without additional measures agricultural emissions are projected to decline by around 4% between 2005 and 2030 (EEA 2023b). Emissions from agricultural peatlands have remained largely stable over the same period (EEA 2024c). Since emissions from all other sectors are projected to decrease more steeply in the future, the share of emissions from agriculture and agricultural peatlands will increase in relation to total net emissions (Figure 2).

Beyond agriculture and agricultural peatlands, emissions occur along the entire food chain, covering also the production of intermediate inputs, transport, processing, marketing, consumption and disposal (Crippa et al. 2021a, FAO 2018). Food system emissions are inherently cross-sectoral and covered by different greenhouse gas reporting categories. They are also not confined to national boundaries. This implies, for example, that some of the emissions driven by food consumption in the EU are reported in the countries of origin of the imports. Similarly, some emissions

Development of greenhouse gas emissions from agriculture and agricultural peatlands in comparison to total net emissions in the EU

→ Fig. 2



Agora Agriculture based on European Union (2023b)

caused by EU agriculture and reported as emissions in the EU can be ascribed to food exports. Furthermore, fuel combustion by machinery and energy use in buildings, which are not counted as part of agriculture in greenhouse gas inventories, would be included in food system emissions.

Emissions from the food system account for a significant share of total greenhouse gas emissions globally and within the EU. Crippa et al. (2021b) estimate that the global food system accounted for approximately 34% of total anthropogenic greenhouse gas emissions in 2015. Based on a life cycle assessment, Sanye & Sala (2023) estimate the food system to be responsible for 38% of the climate footprint of total EU consumption in 2021.

Emissions from agricultural peatlands are reported as part of the Land Use, Land-Use Change and Forestry (LULUCF) sector. The LULUCF sector contains carbon dioxide (CO_2) and methane (CH_4) emissions from land use as well as land-use change, such as afforestation and deforestation, and from forestry. Forests cause positive, but also negative emissions (carbon removals) through storage of carbon in the natural system in trees and soils, as well as in harvested wood products. In 2021, net removals in the LULUCF sector were 230 million tonnes of CO_2 equivalent ($MtCO_2eq$), or about 7% of the EU's total greenhouse gas emissions (EEA 2023c).[4] Forests are the EU's most important carbon sink. However, the sink capacity of forests has declined by a third between 2010 and 2020 (EEA 2022d). This loss of sinks stands in tension with the increasing importance of removing carbon from the atmosphere, as illustrated by an extensive review of climate neutrality scenarios (ESABCC 2023).

The EU's climate target for 2020 has been achieved. However, member states and the European Commission will have to step up efforts to meet the commitment of a 55% reduction in net EU greenhouse gas emissions by 2030 compared to 1990 (ECA 2023a). The "Fit for 55" package, presented in 2021, resulted in the adoption of a range of measures to help achieve this goal (Agora Energiewende 2024).

4 Initial estimates for 2022 show net removals of 244 $MtCO_2eq$ in the LULUCF sector (EEA 2023c).

Infobox 1: The global warming potential of methane as a greenhouse gas

In order to make greenhouse gases with different live spans and other properties comparable in terms of their global warming potential, they are converted to CO_2 equivalents based on an agreed time period. A period of 100 years (GWP-100) has been negotiated and agreed upon under the United Nations Framework Convention on Climate Change (UNFCCC) for the conversion of different greenhouse gases. The Global Warming Potential (GWP) of each greenhouse gas is thus calculated as its relative potency as an agent of climate change compared to CO_2 over the time interval of 100 years. Fossil methane has a GWP of 29.8 over 100 years, while biogenic methane is valued at 27 (IPCC 2021: 1017). Livestock activities contribute the most to global agricultural methane emissions (78%), followed by rice production (22%) (FAO 2023b: 17). Almost all agricultural methane emissions in the EU are from livestock: 80% of the total stems from enteric fermentation and 18% from manure management. Methane emissions from rice cultivation and other sources play a marginal role in the EU (European Union 2022).

Methane has an atmospheric lifespan of about 12 years, unlike CO_2, which lasts for centuries (IPCC 2023). Therefore, methane does not accumulate in the atmosphere and constant emissions do not result in further global warming. The argument has therefore been made that constant methane emissions should be considered climate neutral. To support this viewpoint, a new metric called GWP* has been proposed (Allen et al. 2018, Cain et al. 2019). GWP* primarily assesses changes in methane emissions, valuing constant emissions at 25% of the traditional GWP-100 metric (Cain et al. 2019).

Implementing this weighting would significantly reduce the impact of constant methane emissions on climate change compared to the traditional metric. A weakness of the GWP* concept arises from comparing changes in methane emissions to a historical baseline already influenced by significant increases in methane concentrations due to human activities other than livestock farming (e.g., natural gas production, coal mining, rice cultivation, waste management). There is thus no "cooling effect" through reduced methane emissions, such as often proclaimed (e.g., Cady 2020), but rather a reduction of a past warming effect.

Finally, given the urgency of action to mitigate climate change, not only the long-term climate impact of a greenhouse gas is relevant but also the effects in the upcoming decades. This argument would favour an even shorter period for calculating the GWP and thus weigh methane more than today. For this study, we use the politically agreed GWP-100 of 28 carbon dioxide equivalent for methane emissions (IPCC 2013: 714, Pachauri et al. 2015: 87).

Among others, it established a net carbon removals target for the EU of 310 $MtCO_2eq$ by 2030 through a revision of the LULUCF Regulation ((EU) 2018/841).[5] This removals target was, however, not on track to being met (EEA 2023a). Likewise, the target under the Effort Sharing Regulation ((EU) 2018/842) was increased to a 40% reduction in greenhouse gas emissions in the EU by 2030 relative to 2005 and accompanied by national targets.[6] Although this target covers emissions from agriculture, it includes other sectors as well, including transport, buildings, waste and small industries. A political target for agriculture does not yet exist at the EU level. In its 2023 assessment of member states' draft National Energy and Climate Plans (NECP), the European Commission highlights that further enabling

5 Target introduced in amending Regulation (EU) 2023/839.

6 Target introduced in amending Regulation (EU) 2023/857.

measures are needed to reduce agricultural emissions and enhance carbon sinks (European Commission 2023d).

More pronounced climate efforts will be required in the following decade. The Commission Communication on the 2040 climate target, which sets the stage for a debate on a binding EU climate target for 2040, recommends a 90% net reduction in emissions by that date (European Commission 2024b). Agriculture is expected to be the sector with the highest residual emissions in the EU in 2050. While the extent of agriculture's contribution to net emissions reduction will be subject to negotiations, it will need to be consistent with the EU's climate neutrality objective (ESABCC 2024).

The current EU climate policy framework governing the land use sectors only applies until 2030. One of the main questions for the coming years will be how to design an ambitious, effective and equitable climate architecture for the land use sectors towards 2040, covering both greenhouse gas emissions reductions and carbon removals. One component of this future architecture will be the Carbon Removals and Carbon Farming (CRCF) Regulation (2022/0394(COD)). Approved by EU legislators in 2024, it establishes a voluntary certification framework to facilitate the measurement, reporting and verification of carbon removals and certain emissions reductions. Mechanisms to incentivise emissions reductions from agriculture are also being debated, including the option of a dedicated emissions trading system (Trinomics B.V. 2023).

3.2 Biodiversity protection

Biodiversity loss is a challenge as critical as climate change, and the two are closely interrelated (Bellard et al. 2012, Ceballos et al. 2015). Objectives have been established at the international and EU levels to address the loss of biodiversity. The Kunming-Montreal Global Biodiversity Framework, adopted in 2022 by more than 190 governments worldwide, aims to halt and reverse biodiversity loss (CBD 2022). It sets out a voluntary framework of global goals by 2050 and targets towards 2030. Targets include having restoration measures in place on 30% of degraded ecosystems worldwide and effectively conserving 30% of global land, water and seas. This framework is introduced in the context of the Convention on Biological Diversity, a binding treaty to conserve biological diversity (CBD 1993, Ekardt et al. 2023).

At the EU level, the Nature Restoration Law (NRL) (Regulation (EU) 2024/1991) was approved by legislators in 2024 after prolonged negotiations. The law puts forward the aim to have effective restoration measures cover at least 20% of the EU's land and sea areas by 2030 and all ecosystems in need of restoration by 2050. It also establishes targets for restoration measures in terrestrial, freshwater and marine habitats by 2030, 2040 and 2050. Targets are furthermore specified for urban areas, agricultural and forest ecosystems, rivers and floodplains, pollinators and agricultural peatlands. A target to plant an additional 3 billion trees in the EU by 2030 was introduced. To contribute to these EU-level targets, member states will have to develop National Restoration Plans with context-specific restoration measures. The legislative proposal (COM(2022) 304) acknowledged that measures taken so far have failed to halt biodiversity loss in the EU.[7]

Biodiversity in the EU continues to decline at a high pace. Most protected species and habitats are in a poor conservation status (EEA 2020). The trends for indicator species in agricultural landscapes have been particularly negative. Between 1990 and 2021, the EU Common Farmland Bird Index has dropped by 36% and the EU Grassland Butterfly Index declined by 30%. Agriculture, which covers almost 40% of the EU's land area, is a primary driver of biodiversity degradation (EEA 2020). Among the different reasons, the simplification and specialisation of the agricultural

7 Furthermore, the Habitats Directive (92/43/EEC) and Birds Directive (79/409/EEC) are cornerstones of biodiversity protection legislation in the EU, outlining obligations to maintain or restore a range of natural habitats and species to a favourable conservation status. Other relevant acts include the Water Framework Directive (2000/60/EC), which requires that all bodies of surface water and groundwater achieve good ecological status in the EU by 2027, and the National Emission reduction Commitments Directive ((EU) 2016/2284) which sets targets to reduce air-pollutant emissions, including ammonia (NH_3).

landscape plays a major role since wildlife depends on a high degree of structural landscape diversity with a variety of different habitats and connectivity (Sirami et al. 2019, Tscharntke et al. 2024).

One facet of the problem is the intensity of farming on fertile soils, generally characterised by narrow crop rotations, large fields, a lack of semi-natural landscape features[8], the intensive use of plant protection products and fertilisers and high grazing intensities (Leopoldina et al. 2020). Another facet is the abandonment of agricultural activity on marginal land, which applies in particular to extensively farmed permanent grassland (Schils et al. 2020). This dichotomy shows that it is not agricultural land use per se, but the intensity of farming that threatens biodiversity. European agriculture has a long tradition of arable farming and livestock husbandry, with a rich biodiversity that is specifically adapted to agricultural land use (Grass et al. 2021). The successful conservation and restoration of biodiversity in EU agricultural landscapes can therefore be achieved only in cooperation with farmers.

The production and consumption of agricultural products in the EU impacts on biodiversity not only within the EU, but also in third countries. The import and export of agricultural products implicitly also involves trade in land resources and their ecosystem services. Increasing pressure on global land resources through an increasing demand for food, feed and biomass for the bioeconomy is particularly critical where species-rich and often also carbon-rich natural or semi-natural habitats are converted to agriculture, such as peatlands, mangroves or tropical rainforests (Pendrill et al. 2019).

Forests cover around 39% of the EU land area and are expanding (Eurostat 2023c). Almost all natural forests in Europe have been replaced by forests managed to varying degrees of intensity. Forest management can have a strong impact on forest biodiversity, depending on the intensity and variability of practices. While around 30% of forest habitats were found to be in bad conservation status, they exhibit the highest proportion of improving trends compared to other habitats assessed (EEA 2020). Some indicators specific to forest biodiversity, such as the common forest-bird species protected under the Birds Directive (79/409/EEC), show a positive development. Other indirect indicators also demonstrate a rather positive trend, for example the amount of deadwood in forests and tree species diversity (Forest Europe 2020). At the same time, there are concerning short- and long-term trends, including local forest cover loss (due to wildfire, storms and harvesting) and increasing defoliation, which is a key indicator of forest health (Maes et al. 2020).

During the 2019–2024 legislative period, the European Commission launched a range of policy initiatives aimed at improving the EU's performance in protecting and restoring biodiversity in Europe and reducing its global impacts. These include the EU Farm to Fork (European Commission 2020a), Biodiversity (European Commission 2021f), Forest (European Commission 2021i) and Soil Strategies (European Commission 2021c), as well as the EU Action Plan "Towards Zero Pollution for Air, Water and Soil" (European Commission 2021d). These strategies presented targets for 2030 and announced a range of legislative initiatives. Several of these initiatives affecting the land use sectors have been highly contested politically.

For example, the proposal for a Sustainable Use of Plant Protection Products Regulation (COM(2022) 305) was, after extended negotiations, rejected in its entirety by the European Parliament and subsequently withdrawn by the European Commission. The scope of proposed new rules under the Industrial Emissions Directive (2022/0104(COD)) was significantly curtailed during the legislative procedure. Other policy proposals already appeared in reduced form compared to initial announcements, such as the Soil Monitoring Directive (COM(2023) 416), which was originally expected as a comprehensive "Soil Health Law", and the Forest Monitoring Directive (COM(2023) 728), initially expected to also require national strategic plans for forestry. The Nature

8 Semi-natural landscape features are crop habitats that are farmed within the boundaries of biodiversity conservation and non-crop habitats, such as trees, flower strips, extensively managed grassland, agroforestry and perennial legume-grass mixtures in an arable crop rotation.

Restoration Law was narrowly approved after intense negotiations and following amendments that allow a significantly greater flexibility in implementation.

At the same time, two innovative acts were approved by legislators addressing the responsibility of companies for the sustainability of their value chains. This comes with potentially considerable impacts for global supply chains related to the land use sectors (WBAE 2023). Under the Deforestation-free Products Regulation ((EU) 2023/1115) economic operators will need to prove that certain products put on the EU market (including cattle, wood, cocoa, soy, palm oil, coffee, rubber and some of their derived products, such as leather, chocolate, tyres or furniture) do not originate from recently deforested land or have contributed to forest degradation. The Corporate Sustainability Due Diligence Directive ((EU) 2024/1760) will oblige certain large companies, including in the food sector, to identify and address negative human rights and environmental impacts across their entire supply chains.

Finally, also the EU Common Agricultural Policy (CAP) includes measures aimed at enhancing biodiversity. Since 2023 the latest CAP reform introduced a new delivery model based on national CAP Strategic Plans (Regulation (EU) 2021/2115). This new delivery model gives member states a substantial degree of flexibility to align funding priorities with biodiversity and other sustainability objectives, but does not enforce such an alignment effectively. As a result, the current implementation of the CAP is not in line with the ambition required to address biodiversity challenges (Baldock & Bradley 2023). Moreover, in 2024 EU legislators agreed to revise the CAP to allow greater flexibility in complying with certain environmental conditionalities (Council of the EU 2024b). Many of these changes negatively affect the environmental performance of the CAP.

3.3 Human health and social well-being

Enhancing human well-being is a fundamental goal of the EU and its member states. Objectives related to health and social well-being are codified in a variety of foundational instruments, such as national constitutions and binding international and European conventions.[9] At the EU level, a high standard of human health protection must be ensured in the definition and implementation of all EU policies (Article 168 (1) in the Treaty on the Functioning of the EU (2012/C 326/01)). Member states have also made voluntary commitments. These include social and economic commitments under the Sustainable Development Goals (SDGs) to be achieved by 2030 (UN General Assembly 2015), the goal to halt the rise in obesity by 2025 (WHO 2013) and, at the EU level, to reduce the number of people at risk of poverty or social exclusion by at least 15 million by 2030 (Council of the EU 2022).

The European food system has achieved high levels of food safety, variety and availability (European Commission & Group of Chief Scientific Advisors 2020). On average, households in the EU spent a modest 14% of their incomes on food and non-alcoholic beverages in 2021 (Eurostat 2023d). Food availability is not at risk in the EU, and extreme forms of undernourishment and hunger are very rare (European Commission 2023b). At the same time, the continued prevalence of food poverty, as well as a broad range of negative health impacts linked to the current food system are affecting health and social well-being.

Approximately 8% of the EU population, or around 36 million people, were unable to afford a regular nutritious meal in 2022 (Eurostat 2024d). People exposed to socio-economic vulnerabilities are disproportionally burdened by diet-related diseases (OECD 2019, WHO 2019). While solutions to these problems may lie predominantly in the realm of social policies, food policies, such as the introduction of free school-lunch programmes

9 For example, the International Covenant on Economic, Social and Cultural Rights (ICESCR 1976), the International Convention on the Rights of the Child (ICRC 1989), conventions under the International Labour Organization (ILO n.d.), the European Social Charter (ESC 1961) and the Charter on Fundamental Rights of the European Union (European Union 2012). These establish duties on governments to respect, protect and fulfil social and economic rights.

and other measures to create fair food environments, are also important.

Unhealthy diets contribute to overweight and obesity, which currently affect more than half of the adult population and up to one in three children in Europe (WHO European Region 2022). No country is on track to halt and reverse obesity. According to the OECD (2019), the macroeconomic effect of overweight could be to reduce GDP by around 3% on average annually in the EU between 2020 and 2050. Unhealthy diets are also important drivers of non-communicable diseases, such as cardiovascular disease, type-2-diabetes and different types of cancers. Taken together, non-communicable diseases account for around 80% of the total burden of disease in Europe (OECD & European Union 2022). Moreover, deficiencies in the intake of certain micronutrients have been found in different groups of the population (EFSA Panel on Nutrition, Novel Foods and Food Allergens (NDA) 2022).

The links between the food system and human well-being extend beyond food consumption. The "One Health" concept illustrates how the health of people, animals and the environment are interrelated and interdependent (WHO 2021). Air pollution is one such prominent non-diet-related health impact linked to food systems (Crippa et al. 2022). Another risk includes antimicrobial resistance (AMR), driven by an imprudent use of antimicrobials in both human and veterinary medicine (AMR Review 2015, ECDC et al. 2021, 2024). Land-use changes associated with food production are a driver of the increasing global emergence and spread of infectious zoonotic diseases (UNEP 2020b). Moreover, health risks related to the exposure to hazardous (agro-)chemicals in the food system, including in food production and packaging, have been well-documented, although the aggregate health impacts remain insufficiently assessed (EEA 2019a). Likewise, a range of occupational risks should be considered (EU-OSHA 2019, 2020).

At the global level, food insecurity and hunger have been steadily increasing since 2017. About 9% of the world population, or around 740 million people, faced chronic hunger in 2022. A much larger share of the global population, around 29% or 2.4 billion people, were moderately or severely food-insecure that same year. The interaction between conflict, climate change and economic downturns, resulting in insufficient access to nutritious foods are main drivers of these challenges (FAO et al. 2023). At the same time, obesity and other diet-related diseases are on the rise across the world, co-existing with other forms of malnutrition, including undernutrition and micronutrient deficiencies (Popkin et al. 2020). Due to its favourable agricultural conditions, the EU has an important role to play in global food security. The EU is a large producer and exporter of agricultural products, as well as a large importer of these products. To illustrate the effects of agricultural trade on land use, the so-called "virtual land trade" can be calculated (Qiang et al. 2020). A virtual land trade balance converts trade flows to and from a geographic region into an area needed to produce those traded products. Today, the EU is a net virtual land importer, as further described in Chapter 4.1. In the case of more sustainable consumption patterns in the EU, land demand for food would decline substantially. This would lower the pressure on global land resources.

The Farm to Fork Strategy (European Commission 2020a), introduced by the European Commission in 2020, was a first EU-level attempt to comprehensively address the sustainability of the food system. More than ever, it accorded significant attention to the topics of food consumption and food environments. However, the main food-related policy initiatives under the strategy have remained unpublished. This includes the revision of the Food Information to Consumers Regulation ((EU) 1169/2011), which was expected to propose a harmonised EU-wide front-of-pack nutrition labelling scheme. It also refers to the Legislative Framework for Sustainable Food Systems, a flagship initiative intended to facilitate and accelerate the transition towards a sustainable food system (European Commission 2021h). This leaves member states without a common policy framework enabling a systematic pursuit of food system sustainability objectives across the EU.[10] Moreover, despite a range of social policy initiatives introduced during the 2019–2024 legislative period,[11] the EU's Group of Chief Scientific Advisors has recommended a closer alignment between food and social policies across the EU (European Commission & Group of Chief Scientific Advisors 2023).

3.4 Animal welfare

EU member states have officially recognised animals as sentient beings in 2009, codifying this recognition in the EU Treaties (Article 13, in the Treaty on the Functioning of the European Union (2012/C 326/01)). This means that all relevant EU policies must pay full regard to the welfare requirements of animals, while respecting national specificities. The European Convention for the Protection of Animals kept for Farming Purposes, ratified by the EU, provides that animals should be kept in accordance with the physiological and ethological needs of each species (Council of Europe 1976).

However, many animals are still kept in conditions that fail to meet their nutritional, psychological and behavioural needs. For example, laying hens, sows and calves are often kept in housing systems that strongly restrict their freedom of movement. According to the European Commission (2024j), approximately 40% of the 360 million laying hens in the EU are reared in cages, large numbers of breeding sows in the EU are kept in crates during farrowing and the first weeks of pregnancy, and tail-docking of pigs is still a common practice in almost all member states, despite being prohibited by current legislation (European Commission 2022b).

For the EU population, animal welfare is an increasingly important topic. A Eurobarometer survey in 2023 revealed that 91% of respondents think it is important to prioritise animal welfare to ensure decent living conditions for livestock. Additionally, 84% of respondents express a desire for stronger protection of farmed animals in their country, with 60% indicating willingness to pay more for products sourced from farming systems with high animal welfare (European Union 2023a: 8).

The EU has been recognised for having some of the most comprehensive animal welfare regulations and standards in the world (Animal Protection Index 2023). However, a "fitness check" of EU animal welfare legislation (European Commission 2022b) shows that it has improved the welfare of many animals in the EU to some extent, but the overall level of animal welfare still lags behind societal expectations and scientific requirements. Scientific reports by the European Food Safety Authority (EFSA) in 2022 and 2023 go in the same direction and outline that the existing legislation for farmed animals no longer meets the required welfare standards. Recommendations from EFSA include increasing space provisions, reducing maximum temperatures and reducing journey times to a minimum during transport to improve animal welfare. To improve the welfare of broiler chickens and laying hens, EFSA further advises against practices such as mutilation, feed restriction and the use of cages (EFSA 2023).

The lack of an update of EU animal welfare legislation for more than ten years has contributed to some member states adopting national measures that go beyond EU requirements (European Commission 2022b). The policy space for member states, however, is restricted by potential effects on competitiveness in a common market with lower EU standards (Zöllmer & Grethe 2024). Inconsistent or insufficient regulations make it challenging to enforce and monitor animal welfare standards across the EU effectively, as regulatory frameworks vary between

10 However, several other legislative initiatives were approved or started to apply across the EU. Noteworthy is the application in 2022 of the Veterinary Medicinal Products Regulation ((EU) 2019/6) and the Medicated Feed Regulation ((EU) 2019/4). These regulations support the effort of tackling the contribution of livestock farming to antimicrobial resistance. Furthermore, in 2024, EU institutions agreed to update air quality standards to bring the limit and target values for different air pollutants closer to World Health Organization standards (Council of the EU 2024a). By the end of 2025 the Commission is due to review the National Emission reduction Commitments Directive ((EU) 2016/2284) which currently addresses ammonia emissions (NH_3) that are predominantly emitted from agriculture.

11 For example, the EU Child Guarantee (European Union 2021), the Minimum Wage Directive ((EU) 2022/2041) and Council Recommendation on minimum incomes (Council of the EU 2023b).

regions and countries. Increasing animal welfare standards without accompanying measures would be costly to farmers and bears the risk of lowering domestic animal production while increasing imports of animal products (Grethe 2017). As part of the Farm to Fork Strategy, the Commission announced a comprehensive package to update the EU's animal welfare requirements. So far, only one proposal from this wider package has been published, namely a regulation to improve the protection of animals during transport (European Commission 2023j).

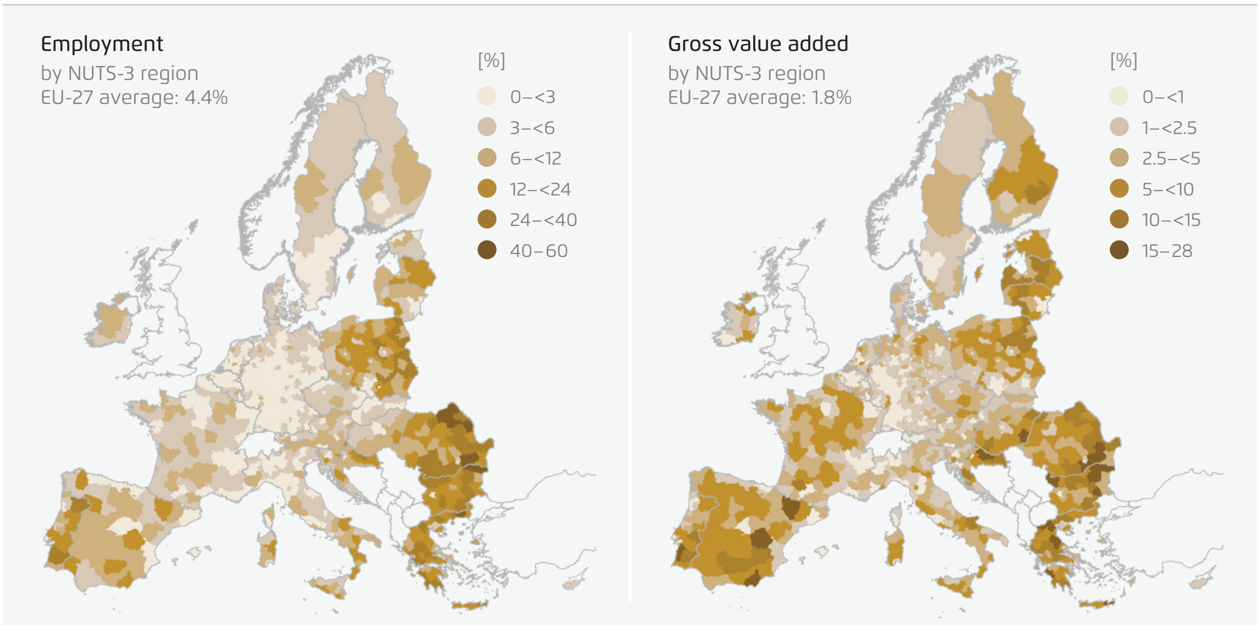
3.5 Economic viability

Ensuring a "fair standard of living for the agricultural community" is one of the economic sustainability objectives of the EU, laid down in Article 39 in the Treaty on the Functioning of the European Union (2012/C 326/01). This objective is to be achieved, among others, by increasing the "individual earnings of persons engaged in agriculture" and is often referred to as "the income objective" of the Common Agricultural Policy (WBAE 2018: 9). In this section, we look at this objective in the context of the land use sectors' role in the wider EU economy, the economic situation of agriculture and forestry, and the challenges they face in achieving other societal objectives, such as climate change mitigation, the enhancement of biodiversity and improving animal welfare.

We first highlight the relevance of agriculture and forestry to the economy at large, since changes in these sectors may have economy-wide repercussions. Secondly, we reflect on the economic situation of the land use sectors. The increasing societal demands for public goods, such as biodiversity protection and climate change mitigation, which are not or only partially remunerated by the market, may involve substantial costs and pose a challenge to farmers who operate under international competition. In addition, the economic viability of the agricultural and forestry sectors is one important element in the societal debate about a fair distribution of the costs of more sustainable land use systems.

The relevance of agriculture and forestry for rural economies varies significantly across different EU

Share of agriculture, forestry and fishing in employment and gross value added in the EU in 2021 → Fig. 3



Agora Agriculture based on Eurostat (2024a, 2024c) regions. On average, the share of agriculture in total EU GDP was about 1.3% in 2021, and employment in agriculture represented 4.2% of total employment (Eurostat 2022a). The forestry and logging industries represented 0.17% of EU GDP that same year (Eurostat 2023c). Figure 3 shows the economy-wide role of the agricultural, forestry and fisheries sectors in different EU regions. Their share of regional GDP ranges between below 1% and 27%, and of regional employment between lower than 1% and up to 60%. The data suggests that structural changes in agriculture could significantly affect the economy in certain EU regions, but the broader economic impact is likely to be relatively small across most regions.

In addition to agriculture and forestry, downstream sectors play an important economic role:

- Agricultural products feed into the wider food chain. The food and beverages processing, wholesaling, retailing and food service industries combined produced some 627 billion euro of value added in 2020 and employed more than 20 million people (Eurostat 2023e).
- Wood harvested from forests provides the raw material for the woodworking, pulp and paper and printing industries. EU wood-based industries generated 136 billion euro of production value, or 7.2% of the total manufacturing industry, in 2020 (Eurostat 2023h). In the same year, 3.1 million people were employed in the EU wood-based industries, or 10.5% of total employment in manufacturing.
- The bioeconomy covers agriculture, forestry, fisheries, aquaculture, food processing and a range of bio-based industries. Beyond the food chain and the more “traditional” non-food biomass uses referred to above, the newer bio-based value chains, such as chemicals, pharmaceuticals and plastics represented 0.5% of EU GDP in 2019. Although still small, they are considered dynamic sub-sectors of the bio-economy (Mubareka et al. 2023).

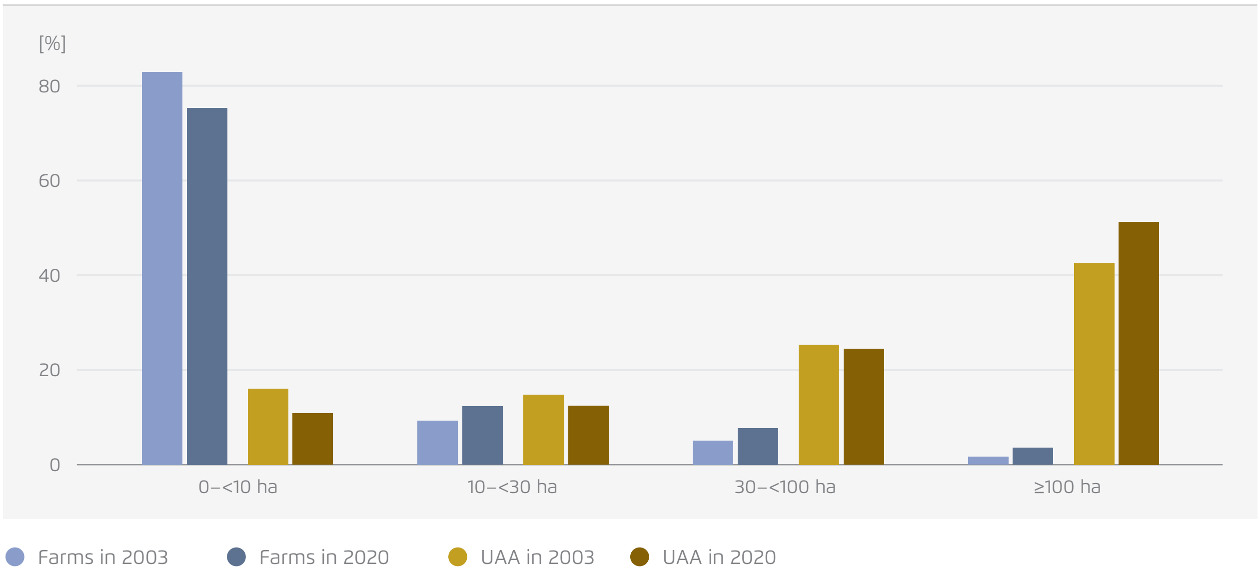
The level of income in the agricultural sector is an ongoing topic of contention. The average entrepreneurial income per worker in agriculture is calculated to be approximately half the average wage in other parts of the economy (European Commission 2020c). This has frequently been invoked to justify political intervention in the sector. The level of earnings of farm households, however, is difficult to ascertain (Hill & Bradley 2015). Usually, only income from farming itself is accounted and not the off-farm income, even if this income is often farm-related, such as from renewable energy. No solid data is available to assess the disposable incomes of farm households, which would provide a more complete indicator of the standard of living of the agricultural community (ECA 2016).[12] Moreover, the diversity among farms in Europe and the differences in levels of economic performance, even sometimes between similar-sized farms, makes it hard to draw general conclusions (WBAE 2018).

While there is no evidence that incomes of farming households are generally low, many farms face economic challenges. This is also caused by the fact that agriculture is a shrinking sector in terms of the number of farms as well as labour. Structural changes, such as farm size growth, have been a reality in agriculture for a long time, with farms specialising and becoming more capital-intensive (Neuenfeldt et al. 2019). As shown in Figure 4, the composition of farm sizes in the EU has changed since 2003. The share of very small farms – still by far the largest group – is decreasing, as is their share in agricultural area. This contrasts with the evolution of farms larger than 100 hectares. Although their share in the number of farms is very low (only 4%), it doubled between 2003 and 2020. These large farms produced on more than half of the agricultural area in 2020.

Although public owned forests are very common in some parts of the EU, around 60% of EU forests are privately owned (Eurostat 2020). The structure of private forest ownership differs greatly from country to country, with properties smaller than one hectare to holdings of several thousands of hectares.

12 The Regulation converting the Farm Accountancy Data Network (FADN) into a Farm Sustainability Data Network (FSDN), approved in 2023, does provide for the option to collect information on the indicative share of off-farm income (Regulation (EU) 2023/2674).

Distribution of EU* farms and Utilised Agricultural Area (UAA) according to farm size in 2003 and 2020 → Fig. 4



Agora Agriculture based on Eurostat (2009, 2017, 2024b). * EU-27, no data for Croatia in 2003

Forest management is dependent on the local soil and climate conditions and characterised by long production cycles of at least several decades to 150 years. Forestry investment thus involves long payback periods. This also means that short-term adaptation to market needs is very limited. While production, harvesting and first processing of wood are generally carried out locally, as it is often uneconomical to transport wood over long distances, the market for semi-finished or finished wood products is global. Forestry is therefore indirectly exposed to global competition.

A special challenge for agriculture and forestry is that they are multifunctional, but not all of their outputs are remunerated through the market mechanism. In addition to producing goods directly remunerated through markets, like food or biomass for energy and material use, the sectors serve multiple other societal functions. Agriculture manages landscapes, shapes ecosystems, drives climate outcomes and affects animal welfare. Agriculture also has social functions within rural areas, but also for society at large (Nowack et al. 2021). In addition to producing biomass for markets, forests support an extensive range of ecosystem services, such as carbon sequestration and storage, providing habitats and biodiversity, water retention or local cooling effect. They also play an important role as landscape features and recreational areas.

A more sustainable land use would result in societal benefits, but if these benefits are not sufficiently translated into incentives for landowners and users, non-sustainable practices may be the more profitable choice from a farm perspective. There needs to be a balance between enforcing sustainability requirements through regulations – such as setting minimum animal welfare standards or maximum nitrogen surplus limits – and providing financial incentives, including payments for delivering public goods or compensating the costs of meeting these regulatory standards.

A crucial factor to consider in this balance is that the agricultural and forestry sectors are closely integrated into international markets. This global integration offers significant economic opportunities. In 2022, for example, the EU had a trade surplus of 30 billion euro for agricultural, fisheries and food products (Eurostat 2023e). Global integration, however, also means that price levels for agricultural products in the EU are largely determined by international markets, which poses a challenge. In a closed economy, the additional costs incurred from enforcing the provision of public goods through regulations would translate in higher market prices, covering at least some of these extra costs. In an open economy, this could lead to reduced competitiveness and increased imports. This is because most of the public goods generated by agriculture and forestry remain unremunerated through private markets, except in certain market niches.

There are ongoing debates about the need to improve prices for farmers and their position in the food supply chain. The European Commission has planned several initiatives, including launching an observatory of production costs, margins and trading practices as well as an evaluation of the Unfair Trading Practices Directive ((EU) 2019/633) (European Commission 2024h). Without prejudice to the possible effects of measures to improve the negotiating position of farmers, options to increase overall price levels are limited in an open market. This issue of not remunerating all outputs through market prices also affects forestry activities, but with two major differences. First, a significant proportion of forests are state-owned or managed by public bodies, which reduces the pressure to generate profits compared to private ownership. Second, long production cycles, spanning decades, require long-term investments and are associated with higher risks, particularly in the face of climate change.

Increasingly, trade measures are taken by the EU to enhance reciprocity in production standards with trade partners. Such measures include sustainability chapters and mirror clauses in trade agreements. They also include autonomous measures set by the EU, such as certain process standards or the establishment of value chain laws.[13] However, the unilateral enforcement of measures on trading partners carries a potential for political conflict, especially if insufficient effort is invested in communication and taking on board concerns about the measures proposed. It can also impair the attainment of wider economic and geopolitical goals of the EU.

As public goods are unlikely to be supported at scale through higher market prices, public incentives that remunerate their provision are important. Such incentives may include public payments or marketing support through investments in value chains. These measures align with the goal of ensuring a viable agricultural sector that can effectively fulfil multiple societal functions. EU law does not articulate an entitlement to receive income support in case an individual livelihood is threatened. Though it does justify government support for enabling farms to maintain the societal functions of agriculture (WBAE 2018).

This implies the need for an EU policy framework in which a fair standard of living can be obtained from producing for the market while contributing to societally desired levels of public goods, including biodiversity, climate, health and animal welfare. The public payments this implies will help diversify farmers income sources. In addition to revenue from selling food, feed or biomass for the bioeconomy, income can be generated through the provision of biodiversity, carbon sequestration, animal welfare and other public goods.

Such payments for the provision of public goods would not necessarily reduce structural change in agriculture. They would however lower the economic pressure to exit the sector. Although economies of scale will likely dominate the provision of most environmental services in agriculture, incentives for social services – such as strengthening territorial identity or promoting agricultural education – can help sustain or create market niches. These niches, which tend to be more labour-intensive, may contribute to maintaining a diverse farm structure (Nowack et al. 2023).

13 For example, see the Deforestation-free Products Regulation ((EU) 2023/1115) or the Corporate Sustainability Due Diligence Directive ((EU) 2024/1760). Likewise, restrictions to import animal products into the EU that are produced with the use of certain types of antimicrobials and the use of antimicrobials as growth promoters is in the process of being implemented (Regulation (EU) 2023/905).

4 A scenario for agriculture and forestry as part of the food system and the bioeconomy

This chapter outlines a scenario for agriculture and forestry in a climate neutral EU by the middle of this century. It describes how the land use sectors, in the context of the food system and the bioeconomy, can contribute to societal objectives, such as climate neutrality, biodiversity protection, health and economic viability. Chapter 4.1 summarises the main societal potentials of the scenario. In the subsequent thematic chapters, the scenario is further detailed for the themes biomass (4.2), food demand (4.3), livestock farming (4.4), arable farming (4.5), agricultural peatlands (4.6) and forest management (4.7). Each of these thematic chapters also proposes elements of an EU policy mix aimed at creating an enabling environment for economic actors in the land use sectors and consumers to contribute to sustainability objectives.

4.1 Key elements and sustainability gains of the scenario

With our scenario, we show that agriculture and forestry, as part of the food system and the bioeconomy, can contribute substantially to climate neutrality, support healthier and more sustainable food consumption, enhance biodiversity in agricultural landscapes and forests, and produce biomass to help replace fossil carbon used throughout the economy. At the same time, animal welfare improves, and the EU becomes a net exporter of virtual agricultural land, thereby reducing the pressure on global land resources and indirectly contributing to food security. Realising such a scenario is ambitious although it is possible if land is used efficiently, and if the demand for food, feed and other biomass is more sustainable than today. This requires an enabling policy environment which provides economic opportunities for farmers, forest owners and rural entrepreneurs, as well as fair food environments for consumers.

Efficient land use is one of the two main building blocks of our scenario. Land use fulfils diverse societal demands, ranging from the production of food, wood and other raw materials to the provision of habitats and other ecosystem services, such as carbon sequestration. However, land is limited in the EU, and trade-offs exist between different land use objectives. Efficient land use is important to optimise returns under any given demand scenario, to mitigate trade-offs and to deliver multiple benefits simultaneously.

A more sustainable demand for food, feed and biomass for material and energy use is the second building block of our scenario. Different consumption patterns of agricultural and forestry products are associated with different effects on climate, biodiversity and health. They also differ in their demand for land, which can either aggravate or help resolve trade-offs between land use objectives. Only the combination of efficient land use and sustainable demand enables the land use sectors to realise their full potential to contribute to societally agreed sustainability objectives. With our scenario we show one possible way of doing this.

A more sustainable demand for food and feed involves food consumption patterns that are rich in plant-based foods and lower than today in animal-based products. The reduction in the overall consumption of animal products by about 50% goes together with a decrease in livestock production in our scenario. This leads to a significant reduction in the demand for animal feed. Figure 5 shows a 48% reduction in the use of arable land for growing animal feed in the EU in 2045 compared to 2020, making land available for other uses. The demand for imported feed also declines and so too does the arable land area needed to produce that feed in other parts of the world. This reduces pressure on global land resources and can indirectly contribute to global food security, biodiversity and climate change mitigation. Such a shift in food consumption is a contribution to healthier diets while reducing negative environmental effects related to production. Food waste reduction is another component of sustainable demand. We assume a 50% reduction in food waste in our scenario, which alleviates pressure on land resources and helps reduce greenhouse gas emissions.

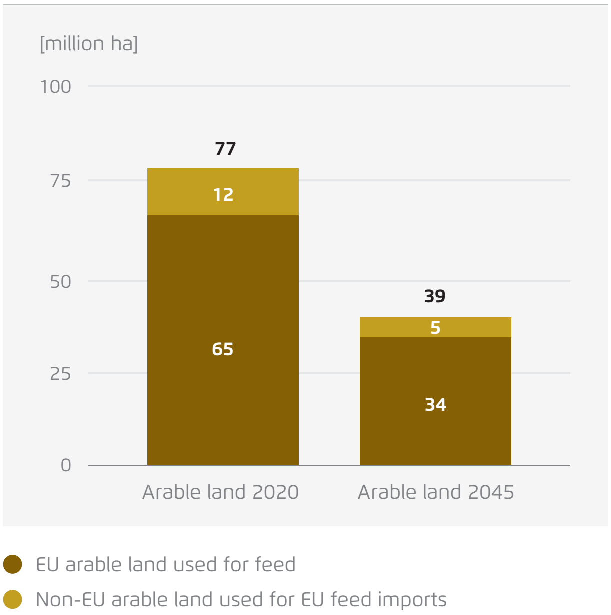
Sustainable demand is also important for biomass uses other than for food and feed. In our scenario, we project the overall demand for non-food, non-feed uses of biomass to increase by about 20% by 2045. There are two main drivers for this:

- An increase in the material use of biomass by about 70% to replace fossil feedstocks across the economy due to the economy-wide transition towards climate neutrality.
- A gradual shift away from using biomass for bio-energy production, which we assume will decrease by 15% between 2020 and 2045, as electrification becomes available for a wider range of uses.

Bioenergy requires 50 to 100 times more land per unit of energy produced than energy produced by solar and wind (Van Zalk & Behrens 2018). In only a few cases it is an efficient basis for electrification, for example biogas made from agricultural residues (Chapter 4.2). Likewise, we assume that first-generation liquid biofuels will be largely phased out due to more efficient alternatives, except in specific cases like heavy machinery for farming operations such as tillage and harvesting.

Global arable land used for EU feed in 2020 and 2045

→ Fig. 5



Agora Agriculture based on CAPRI results and European Commission (2022e)

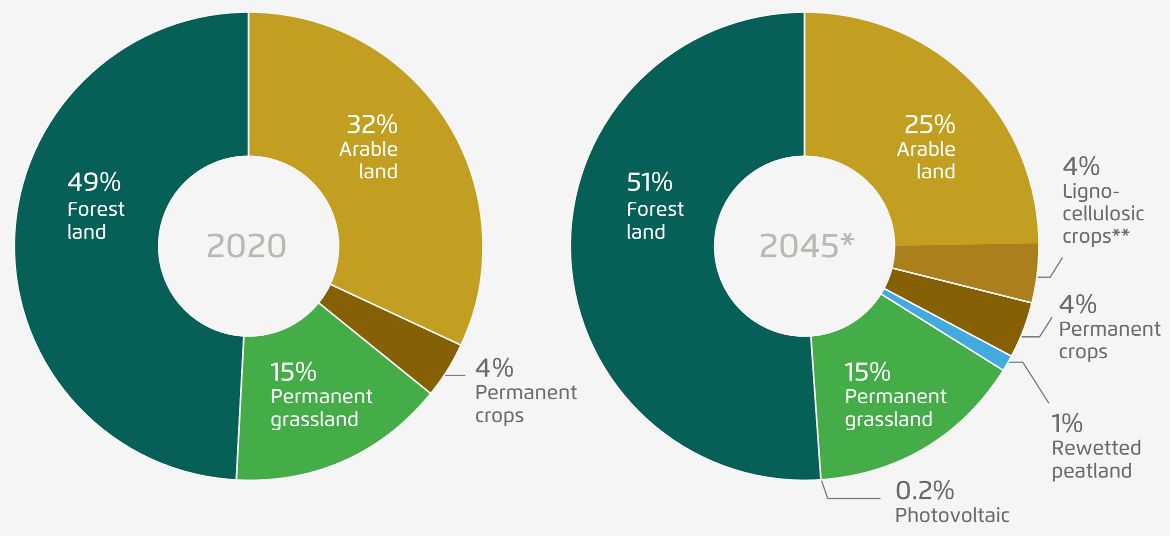
While the sustainable demand for food, feed and biomass is important for land use efficiency, land is still scarce, and efficiency gains are also required in crop production. We expect average crop yields to increase, driven by the uptake of improved agricultural technology, machinery, irrigation and progress in plant breeding, narrowing yield gaps across regions.

Figure 6 illustrates the distribution of land use in our scenario in 2045 compared to 2020. It shows that arable farming in the scenario changes, primarily driven by a reduced demand for feed and an increased demand for biomass. Reductions in fodder-grain production on arable land are accompanied by an increase of other crops such as lignocellulosic crops (e.g., fast-growing trees) and paludiculture[14] crops (e.g., reed or cattail) on rewetted peatlands for the bioeconomy. Though not shown in the figure, the production of vegetables on arable land increases substantially.

In the 2045 scenario, lignocellulosic crops are planted on around 8% of agricultural land, mostly on arable land (equivalent to 4% of the combined agricultural and forest land). They close the gap between the 30% increase in demand for woody biomass and the 10% decrease in forest harvest included in our scenario. This reduced harvest is due to adapted forest management. Additionally, the forest area expands by 5 million hectares by 2045. Both measures allow forest services to be maintained and enhanced for the future, including wood harvests, carbon sequestration and biodiversity functions (Chapters 4.2 and 4.7).

14 Paludiculture is a peat conserving form of agricultural production and forestry on rewetted peatland (Nordt et al. 2022). In this study we focus on agricultural production.

Land use in the EU agricultural and forestry sectors in 2020 and 2045 → Fig. 6



Agora Agriculture based on CAPRI results. *due to rounding figures add up to more than 100%; **e.g., short rotation coppices, agroforestry, miscanthus on arable land

The area under permanent grassland remains stable. The reduced livestock population allows for more grazing opportunities and grassland feeding. This is relevant from climate, biodiversity and animal welfare perspectives (Chapter 4.4). Also, the area share of permanent crops remains almost constant in our scenario, although there are shifts within the land use category, such as an increase in the share of fruit trees (Chapter 4.5).

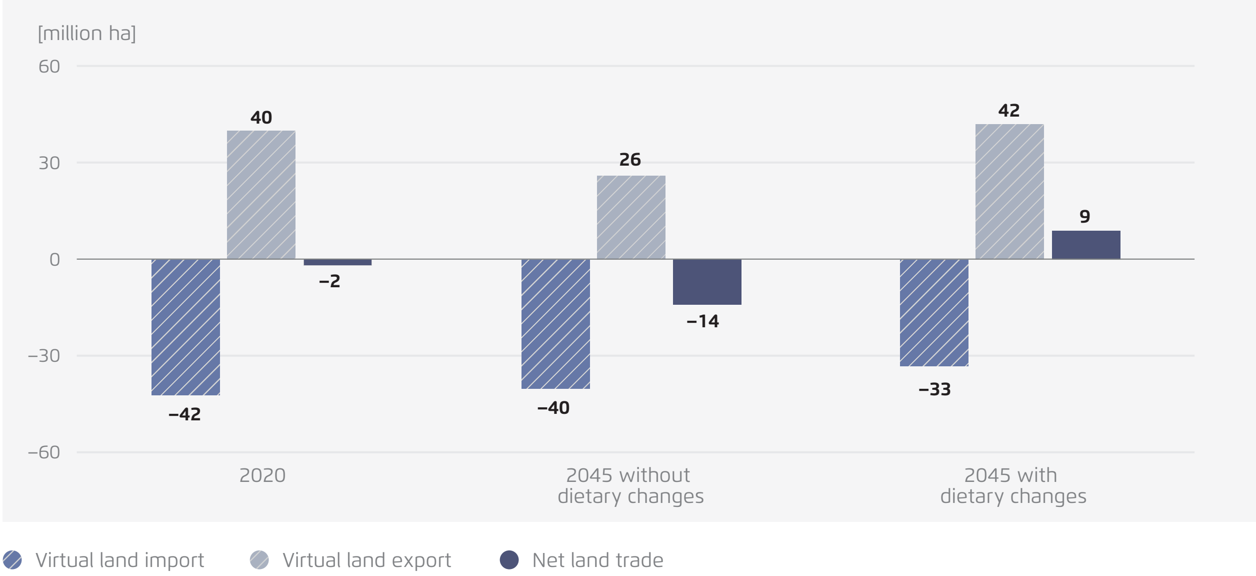
Only around 2% of the agricultural area in the EU is rewetted by 2045 to reduce greenhouse gas emissions from drained agricultural peatlands (equivalent to 1% of the combined agricultural and forest area). In some regions, however, the rewetting of agricultural peatlands will have a substantial impact on land use patterns. Most of the rewetted peatlands will continue to be used productively. We assume 80% of the rewetted peatlands to be dedicated to paludiculture biomass production. The remaining 20% of these rewetted areas are used for energy production through solar photovoltaics (PV) and for biodiversity.

We project an installed capacity of 711 GW of ground-mounted solar PV on agricultural land which implies an additional installed capacity of 612 GW in our scenario compared to 2020. The resulting land demand is about 0.4% of total agricultural area (equivalent to 0.2% of the combined agricultural and forest area), therefore not impacting overall agricultural land use significantly.

The combination of efficient land use and sustainable consumption allows the land use sectors to contribute substantially to societal objectives within the EU (see below). It also allows the EU to increase net exports to other countries. As Figure 7 shows, the EU turns from a net importer of virtual land in 2020 to a substantial net exporter in 2045. We calculate that the EU imported a net of 2 million hectares of virtual land in 2020 and it exports a net of 9 million hectares in 2045.[15] This development is especially driven by a reduction in feed imports and increasing net exports of dairy products while most other trade balances do not change strongly

15 For these calculations, we convert product trade into embedded virtual land using world average yields (Annex Chapter 2). This approach eliminates effects caused by shifts in import origins and changes in yield gaps between the EU and non-EU countries over time. The resulting net virtual land trade provides a good indicator of the EU's net contribution to global food production, independent of the local yield level. This differs from other approaches as applied by De Laurentiis et al. (2024), which are better able to depict the specific land embedded in trade at a given point in time and for given countries of origin and destination.

EU net virtual land trade based on world average yields → Fig. 7



Agora Agriculture based on CAPRI results

between 2020 and 2045. In addition, the EU is largely self-sufficient in biomass for material and energy use in 2045 due to the assumed increase in production of biomass with fast-growing trees (Chapter 4.2). The aggregate positive EU trade balance is relatively robust against shifts to alternative product compositions. For example, if a higher share of wood products or biochemicals would be imported, a higher share of other commodities, such as grains, could be exported.

Changes in food consumption patterns are essential for realising the contribution of agriculture and forestry to societal objectives within the EU as well as for lowering the pressure on global land resources. We conducted a sensitivity analysis which shows that applying our scenario with all the anticipated changes in agriculture, while maintaining 2020 consumption patterns and not reducing food waste, would result in the EU becoming a net virtual land importer of 14 million hectares in 2045, rather than a net exporter of approximately 9 million hectares in that same year. The larger EU imports and the smaller EU exports of agricultural products would lead to increasing agricultural production in non-EU countries and additional greenhouse gas emissions in these countries of 59 million tonnes of carbon dioxide equivalent ($MtCO_2eq$) compared to our main scenario.[16]

In the following paragraphs we highlight how our scenario contributes to mitigating climate change, enhancing biodiversity, supporting health and social well-being, improving animal welfare and creating economic opportunities for the land use sectors and rural areas.

Climate change mitigation

Figure 8 shows that greenhouse gas emissions from agriculture and agricultural peatlands can be reduced by more than 60% by 2045 compared to 2020.[17] This

16 Greenhouse gas emissions figure derived from a sensitivity analysis conducted in CAPRI (Chapter 4.3.2).

17 Greenhouse gas emissions figures are derived from the CAPRI model and calibrated to better align with national inventories (Annex Chapter 1). The emissions represented in this figure encompass emissions from the reporting category agriculture and the CO_2 and methane emissions from agricultural peatlands, which are categorised as emissions from agricultural soils and reported under the reporting category LULUCF. In calculating the emissions from agricultural peatlands, we combine data on the area of organic soils from the CAPRI model with emission factors from the IPCC's methodological guidance on national greenhouse gas inventories for wetlands (IPCC 2014) and adjust some emission factors for grassland according to Martin & Couwenberg (2021). See the Annex Chapter 7.2 for further details.

is substantial in light of the 8% reduction in emissions from agriculture and agricultural peatlands achieved during the 25 years between 1995 and 2020 (EEA 2024c).

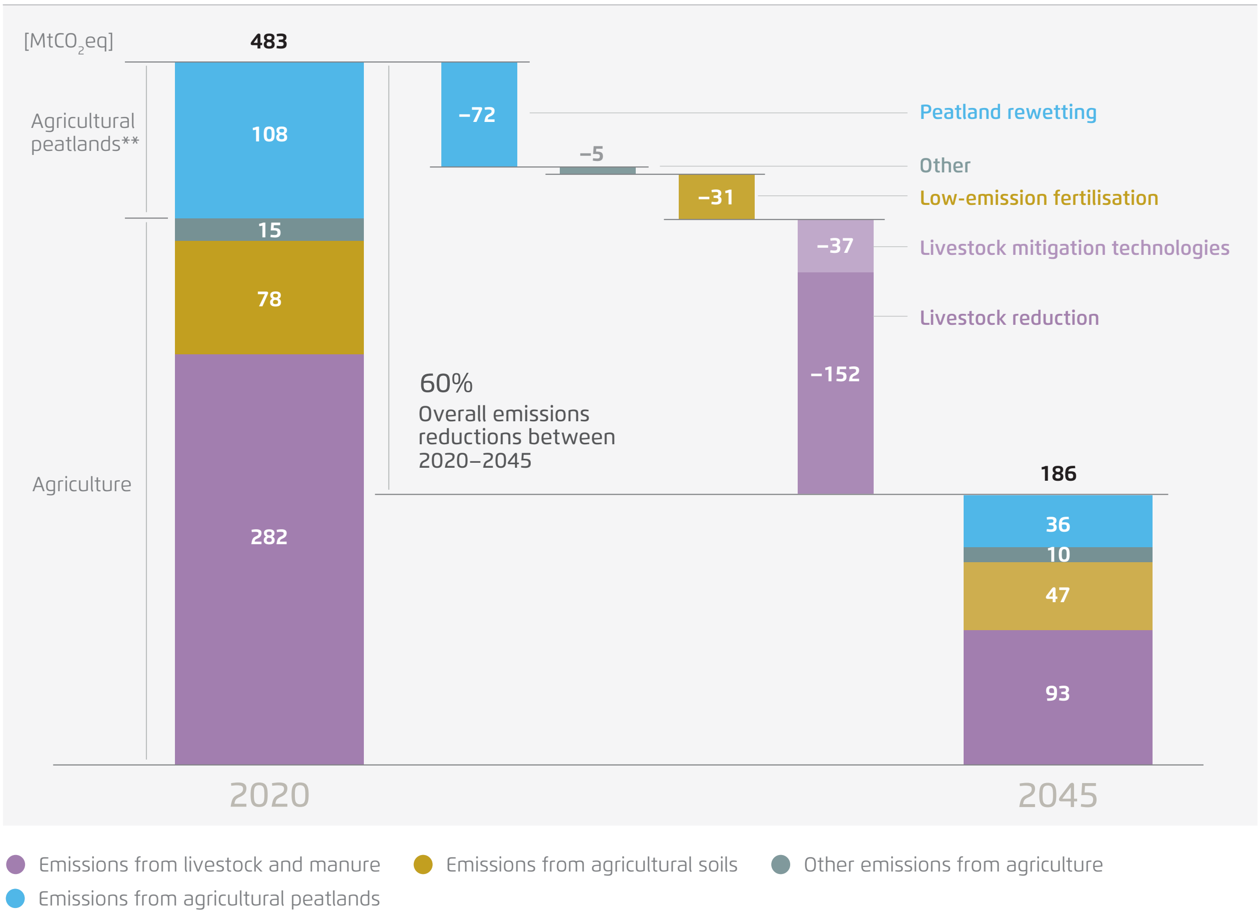
This sizeable change is achieved due to emissions reductions in three main areas:

1. Emissions from livestock, covering both enteric fermentation and manure management, go down by about 67%. Approximately 81% of this reduction is attributable to reducing livestock numbers. The other 19% result from the uptake of emissions mitigation technologies related to feed and manure management.[18]
2. Emissions from agricultural peatlands decrease by 67% as a result of rewetting about 80% of today's agricultural peatlands and using the other 20% predominantly as shallow-drained grassland.

18 Nitrous oxide (N_2O) emissions from manure application, which are usually categorised under emissions from agricultural soils, are included as emissions from livestock and manure.

Reduction of greenhouse gas emissions from EU agriculture and agricultural peatlands between 2020 and 2045*

→ Fig. 8



Agora Agriculture based on CAPRI results. * N_2O emissions from manure application under "livestock and manure", N_2O emissions from organic soils under "agricultural peatlands"; ** estimate for emissions from agricultural peatlands with CAPRI data on organic soils and emission factors from IPCC (2014), see Annex Chapter 7

3. Emissions from agriculturally used mineral soils fall by an approximate 39% due to low emission fertilisation strategies (reduced nitrogen surpluses and increased nitrogen use efficiency) (Chapter 4.5.1).

In addition to these emissions reductions, we foresee other climate benefits related to our scenario, including emissions reductions and carbon removals. The additional gains below are based on rough estimates.

Additional estimated contributions to **emissions reductions**:

- By 2045, some 64 million tonnes of renewable carbon are supplied through woody biomass produced on agricultural land. This biomass is used to substitute fossil feedstock for energy and material use. Applying a rather conservative substitution factor of 0.55,[19] at least 131 MtCO_2 emissions could be mitigated annually through using the wood from fast-growing trees when these are fully established in 2045 (Chapter 4.2).
- Emissions related to energy consumption in agriculture and forestry summed to nearly 74 MtCO_2eq in 2020 (European Union 2023b).[20] These emissions can largely be avoided by electrifying stationary energy use and sourcing it from renewable energy. Vehicles operating for short intervals or within the farm gates can also be electrified. In contrast, off-road vehicles performing heavy-duty work are still likely to require energy-dense liquid fuels in the future (KTBL 2023). Some combustion engines may therefore still run on biofuels. We did not go into detail on these aspects in our scenario.
- Agricultural land is used to produce energy through wind and solar PV. We specifically focus on solar PV production due to its higher land demand compared to wind energy. We project an installed capacity of 711 GW of ground-mounted solar PV in our scenario, which implies an installed capacity of 612 GW in 2045 on top of the current capacity. To illustrate the potential of this change, we calculate the avoided emissions very roughly using the emission factors of today's EU energy mix. On this basis, the additional installed capacity of ground-mounted solar PV would save 127 MtCO_2 per year. Note, however, that this emission factor declines with an increasing share of renewable electricity. The installed capacity is divided between different types of ground-mounted PV:

    - Conventional solar PV, focused on power generation (63% of the total, or 384 GW),
    - Agri PV and biodiversity PV, enabling a combination of power generation, agricultural production and biodiversity enhancement (25% of the total, or 155 GW),
    - Peatland PV, allowing power generation on rewetted peatlands (12% of the total, or 73 GW). Solar PV on rewetted peatlands contributes about 7% to the total estimated EU installed solar capacity in 2045. This is possible if solar PV modules are installed on 4% of rewetted peatlands.

Estimated contribution to **carbon removals**:

- Forest net carbon removals in 2045 are estimated at approximately 290 MtCO_2eq, similar to 2020 levels (Chapter 4.7). However, the level of removals depends on the effects of climate change on forests, adaptation efforts and forest management strategies that support the forest sink. This projection includes an additional sink on 5 million hectares due to afforestation.
- The annual carbon removals by harvested wood products are projected to increase by 17 MtCO_2, increasing from 41 MtCO_2 in 2020 to

19 This is the factor for wood replacing natural gas for industrial heat production using IPCC default values (Leturcq 2020). This study makes the case to strengthen material use of wood where we assume the substitution factor to be greater. This factor is based on the assumption of carbon neutrality of wood, which should not apply to forest wood. Also, if the use of agricultural land is associated with indirect Land-Use Change (iLUC), this factor has to be adjusted.

20 These emissions are reported under United Nations Framework Convention on Climate Change (UNFCCC) category Energy, sub-heading Agriculture/Forestry/Fishing, 1.A.4.c.i Stationary and 1.A.4.c.ii Off-road Vehicles and Other Machinery (excluding 1.A.4.c.iii Fishing). One third of the emissions comes from stationary use and two thirds from mobile combustion. Stationary energy use means mostly fossil heating-energy for stables, greenhouses and drying of grains. Mobile combustion refers primarily to agricultural vehicles and machinery.

approximately 58 $MtCO_2$ in 2045. This is attributed to the increase in material use of woody biomass (Chapter 4.7).

- Carbon removals on arable land are achieved through permanent land-use changes. In our scenario, planting hedgerows on 0.6 million hectares in the period between 2025 and 2045 results in negative emissions of around 112 $MtCO_2$ for this period, or around 5 $MtCO_2$ on average per year (Chapter 4.5).
- Moreover, around 13 million hectares of fast-growing trees are established on agricultural land, resulting in negative emissions of about 660 $MtCO_2$ in the period between 2025 and 2045, or around 30 $MtCO_2$ on average per year (Chapter 4.2).

Biodiversity

While we quantify the contribution of our scenario to climate change mitigation, we do not quantify its effects on biodiversity. Quantifying changes in biodiversity is far beyond the scope of this study and the dynamics of biodiversity are complex. However, the measures implemented in our scenario for conserving and enhancing biodiversity, as well as our assumptions about their spatial and temporal scales, are grounded in meta-studies on the relationship between land use and biodiversity. The biodiversity measures we prioritise for EU agriculture and forestry are widely applicable, and their effectiveness is well documented.

The intensity of agricultural and forestry management in the EU impacts local biodiversity, as well as biodiversity in other countries through price-mediated indirect land use effects. Lower yields in the EU lead to higher imports or lower exports if demand in the EU remains the same. The major challenge is therefore to find a balance between high land productivity and providing species-rich habitats. Our scenario aims to enhance biodiversity within the EU, while also reducing the pressure on land resources globally. This can only succeed if measures to protect biodiversity in EU agriculture and forestry are accompanied by a change in the consumption of food, feed and other biomass.

Protecting biodiversity needs a landscape perspective. Concrete measures for biodiversity must be implemented by individual farmers and forest owners but require cross-farm and landscape-level coordination to be efficient (Chapters 4.5 and 4.7). To support biodiversity on arable land, the scenario includes a combination of measures aimed at having a low impact on land availability for production and agricultural productivity. The package of measures includes the provision of semi-natural habitats, structurally diverse cropping systems, integrated plant protection and low-emission fertilisation (Chapter 4.5.1).

Instead of fixed set-aside obligations for each farm, we propose 20% semi-natural[21] landscape features at landscape level. When calculating the regional land required for semi-natural habitats, we take into account existing landscape features both on and adjacent to agricultural land, including elements of the scenario such as semi-intensive grassland management and integration of fast-growing trees into the agricultural landscape. This means that additional semi-natural features on arable land are needed only in those landscapes where the share of 20% is not yet reached. According to our analysis, an average of around 5% of arable land in the EU needs to be dedicated to semi-natural features by 2045, though with large regional differences.

Beyond biodiversity, semi-natural features provide valuable co-benefits, such as for carbon sequestration, soil conservation, water protection and biocontrol. The multifunctionality of semi-natural landscape features is particularly evident in hedges, fast-growing trees and other agroforestry systems. These not only provide a strong ecological contrast in agricultural landscapes and sequester carbon, but also provide valuable biomass for the bioeconomy (Chapter 4.2).

21 The term "semi-natural landscape features" covers both non-crop habitats (e.g., hedges, flowering strips, fallow land, ditches and ponds) and crop habitats that are farmed within the boundaries of biodiversity conservation (e.g., perennial legume-grass mixtures, extensively grazed or mown permanent grassland and agroforestry systems).

Other management practices also increase heterogeneity in agricultural landscapes with benefits for biodiversity. This includes diverse, site-adapted crop rotations and that the average field size at landscape level is smaller than 6 hectares. This is accompanied by halving the use and reducing the risk of plant protection products and halving nitrogen balance surpluses by 2045 compared to 2020.

Another key to enhance biodiversity in agricultural landscapes is the maintenance of permanent grasslands. Extensive permanent meadows and pastures are hotspots of biodiversity. Land productivity and biodiversity conservation can also be balanced in permanent grassland. This includes controlled grazing, site-adapted fertilisation and regular maintenance. In our scenario this is supported by using permanent grasslands for feeding livestock but with reduced livestock numbers and adapted grazing strategies. Reduced livestock density also helps to decrease regional nitrogen balance surpluses. Nitrogen input from manure is cut by more than half, providing environmental benefits for biodiversity but as well for climate protection, air, water and soil quality.

Likewise, biodiversity in forests can increase through management choices related to a modest reduction of harvests in forest, the implementation of forest-adaptation strategies and through afforestation (Chapter 4.7).

Health and social well-being

In our scenario, the share of plant-based foods in overall food consumption across the EU increases compared to 2020. We foresee a doubling in the intake of fruits and vegetables and an increase in the consumption of legumes. The average intake of animal products declines by about 3% per year, or by 51% in total between 2020 and 2045, with different shares of reduction for different animal products. Sugar intake also declines.

Food demand in our scenario represents an aggregate population-level intake of different food groups across member states. It is not a dietary recommendation for individuals. However, individual consumption patterns in line with this scenario can contribute to a reduction in diet-related diseases, positive climate impacts and an efficient allocation of land resources. The consumption scenario by 2045 is in line with recent developments in national dietary guidelines in European countries (Chapter 4.3).

In current debates, food security is often referred to as being incompatible with making further steps towards sustainability in the land use sectors. In our scenario, however, we show that the combination of an efficient use of land and sustainable consumption contributes to food security both inside and outside the EU. Food security is "a situation that exists when all 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" (HLPE 2020: 10). It is a multidimensional concept encompassing food availability, access to food, nutritional outcomes, supply chain resilience and environmental sustainability (European Commission 2023b).

In our scenario, sufficient food is available in the EU to support nutritionally healthy diets. Self-sufficiency rates of most relevant food products remain stable or increase until mid-century (Chapters 4.4 and 4.5). Additionally, the measures in the scenario contribute to a resilient food system and ecological stability. Moreover, fair food environments contribute to the availability, affordability and appeal of foods for healthy and sustainable diets, contributing to meeting dietary needs. Finally, social policy measures as part of the scenario enhance access to healthy diets for socio-economically vulnerable consumers (Chapter 4.3). As highlighted above, the EU contributes not only to domestic, but also to global food security, at least indirectly by reducing pressure on global land resources by increasing virtual net exports of land.

Although we did not estimate changes in food costs for consumers due to the multiple factors influencing food prices in long-term projections, research indicates that in upper-middle-income to high-income countries, healthy and sustainable consumption patterns that are plant-rich result in lower costs compared to current diets (Springmann et al. 2021). In our scenario, food prices are mainly tied to world market prices, as we do not foresee a major role for protective trade policies.

Animal welfare

Another element of the scenario is the improvement of animal welfare through various advances in husbandry and management practices for cattle, pigs and poultry. This includes the provision of more space, diverse environments adapted to each species, outdoor access and greater opportunities for animals to express their natural behaviours. Common practices include outdoor runs, free-range housing and enrichments such as straw. Non-curative procedures, such as tail docking in pigs and beak trimming in poultry, are mostly eliminated. The use of cages for poultry has been phased out. For cattle and other ruminants, a greater proportion of animals have access to pasture (Chapter 4.4). To support the implementation and economic viability of these improvements in an environment of international competition, increasing animal welfare needs to be rewarded through public payments.

Economic opportunities for the land use sectors and rural areas

Our scenario implies a range of economic opportunities and challenges for agriculture and forestry. It involves substantial changes in consumption and production, with considerable implications for some of the current business models. For example, while a shift in consumption patterns towards more plant-based foods is critical for sustainability, the effects on livestock production, a central economic pillar of the agricultural sector, will be substantial. Also, the rewetting of agricultural peatlands will result in significant changes to production in some regions and a reduction in forest harvests will carry implications for forest owners.

At the same time, opportunities can arise from the overall increase in demand for products and services from agriculture and forestry. For example, the growing demand for biomass for materials can create opportunities for forestry and agriculture. There is significant scope for producing renewable energies, such as solar PV, wind and residue-based biogas. New food demands, such as for fruits and vegetables, which offer high added value per hectare, can create new market opportunities. Furthermore, the provision of public goods, such as biodiversity protection, carbon sequestration and animal welfare, can become real business models.

While these opportunities are real, they cannot be expected to always translate into concrete business models without a conducive policy environment. For example, it will be crucial to incentivise the establishment of new value chains in the bioeconomy (Chapters 4.2, 4.5–4.7, 5.4 and 5.5). Likewise, barriers to the increased production of fruits and vegetables and alternative protein sources need to be overcome (Chapters 4.3 and 4.5). Furthermore, given that the market typically rewards the provision of public goods only to a very limited extent, providing public goods may be a burden to the land use sectors, rather than a source of income (Chapter 3.5). Therefore, in an open market we foresee an important role for public payments to provide incentives for the provision of public goods. Finally, supporting innovation is important, for example through a further development of the EU legal framework for plant breeding, sustainability labelling and the use of food waste in animal feed, as well as administrative simplification, such as through a European Common Agricultural Data Space (Chapter 4.5.3).

The provision of public goods has a value for society, but usually involves costs for those who provide them. If the provision of public goods is rewarded through public or private funding, it can become a business model and thus part of the income of farmers and forest owners (Chapters 5.1 and 5.2). The level of public payments for public goods will be based on societal negotiations, related among others to applicable minimum regulatory standards, the cost of providing the services and their value to society. This translates into income opportunities if the required measures are incentivised with public and private payments that equal or exceed the full cost of implementing them, including all costs for labour, land and capital.

Below, we estimate the cost of providing a selected number of public services. We also estimate the potential value of carbon removals related to some of these services. Both calculations are very basic and rough. However, taken with caution, they provide an idea about the scope for potential business models related to the provision of public goods by farmers and forest owners:

- The provision of a higher animal welfare level across the EU may result in additional annual production costs of about 10–20 billion euro (Chapter 4.4.4). Public payments to remunerate a higher animal welfare level can be particularly important for farmers that are adversely affected by the overall decreasing livestock production.
- The creation and management of biodiverse agricultural landscapes would result in investment costs, as well as annual costs incurred and income foregone for: 1) the establishment of semi-natural landscape features, 2) the diversification of crop rotations, 3) the management of smaller cropping units and 4) a less intensive use of grassland. We estimate these costs at about 90 billion euro investment cost for the period between 2025 and 2045, and at 9–20 billion euro annually (Annex Chapter 6).
- Rewetting drained agricultural peatlands reduces greenhouse gas emissions effectively but also comes with opportunity and investment costs for farmers. We estimate short-term opportunity costs of up to 1 billion euro annually and about 12 billion euro in total for the period between 2025 and 2045 (Chapter 4.6.4).
- We foresee approximately half the afforestation previewed in our scenario to be active afforestation linked to investments needs. We calculate some 2–3 billion euro of investment annually between 2025 and 2045. The cost of forest adaptation measures we estimate at 12 billion euro annually over the same period (Chapter 4.7.3). Both measures support critical forest functions, including biodiversity protection and carbon removals. These measures are also important to maintain forest economic activities in the face of climate change. Payments in support of these efforts can strengthen forest owners' businesses.

Implementing certain measures, including those referred to above, can generate carbon removals. As the EU economy transitions to climate neutrality, these measures will generate societal value, which can be estimated based on future carbon prices. Estimates of future carbon prices are difficult to make, ranging from less than 100 to well over 200 euro by mid-century per tonne of CO_2. A more sophisticated calculation would discount the carbon price for land-based removal according to the risk of reversibility. We instead use a conservative carbon price estimate of 100 euro per tonne of CO_2 for a rough estimation of the value of the carbon removals listed above:

- The introduction of hedges and fast-growing trees on agricultural land is projected to generate negative emissions of 35 $MtCO_2$ annually on average for the period 2025 to 2045. Based on the conservative estimate of a future carbon price of 100 euro per tonne, this would translate to a potential societal value of over 3.5 billion euro annually (Annex Chapter 6).
- Harvest reduction and afforestation may lead to an average of 50 $MtCO_2$ of negative emissions annually for the period up to 2045. With the assumed carbon price of 100 euro per tonne, this translates into a societal value of around 5 billion euro annually. As harvest reduction as well as afforestation is costly for forest owners, it is plausible that economic incentives are established for generating this societal benefit (Annex Chapter 8).
- Finally, harvested wood products would generate 17 $MtCO_2$ of additional negative emissions, resulting in a societal value of about 1.7 billion euro annually with a carbon price of 100 euro per tonne (Annex Chapter 3).

4.2 Biomass

4.2.1 Scenario

Forestry and agriculture can play an important role for the entire economy to become climate neutral, by providing biomass to other sectors. Land is not only used to produce food and feed, but also to produce biomass for materials and energy use. Throughout this chapter, the term "biomass" refers to biomass for energy and material use. Material use includes traditional uses such as wood in construction, as well as use as a feedstock in the chemical industry to produce bioplastics or other biochemicals.

The biomass supply from rewetted agricultural peatlands and from forests is described in detail in Chapters 4.6 and 4.7. This chapter outlines our scenario for biomass supply from lignocellulosic crops, such as fast-growing trees or miscanthus (definition in Section B), energy crops, residues, waste and recycled materials. The scenario includes the following elements:

A) Efficiently utilising biomass to defossilise the economy
B) Establishing new supplies of lignocellulosic biomass on 8% of the EU's agricultural land

Subsequently, we analyse the environmental (Chapter 4.2.2) and socio-economic (Chapter 4.2.3) implications following these changes. In Chapter 4.2.4 we discuss EU policy options to incentivise and support the changes outlined in the scenario.

A) Efficiently utilising biomass to defossilise the economy

Achieving climate neutrality in the EU economy requires a phase-out of fossil carbon across all sectors. In the scenario, part of the fossil feedstock for materials and energy is replaced by bio-based alternatives. To develop the scenario for biomass use in 2045, we reference two external studies that largely adhere to the principles of an efficient biomass allocation outlined below. Biomass demand for material use, including the demand from the chemical industry, is derived from the "high-value scenario" by Material Economics (2021). For bioenergy demand we draw on the scenario "Breaking free from fossil gas" by Agora Energiewende (2023).

Based on these studies, the total use of biomass in the EU increases by around 20%, from about 2 400 TWh in 2020 to approximately 2 900 TWh in 2045 (Figure 9). This is driven by an increasing demand for material use of biomass. Biomass use for materials increases by around 70%, from about 1 000 TWh in 2020 to nearly 1 700 TWh in 2045. This is caused by the rising demand for timber and wood products in construction, as well as for the chemical industry.

In contrast, the amount of total bioenergy production decreases by around 15% compared to 2020, from about 1 400 TWh to approximately 1 200 TWh. Bioenergy currently accounts for 59% of the total use of biomass. In the scenario this share decreases to 42% by mid-century. This shift is largely due to the increase in material use and the adoption of more efficient alternatives for energy production, such as in heating and the electrification in transport.

Three main considerations guide the efficient use of biomass in our scenario:

- The finite nature of **biomass resources and trade-offs** between the production and extraction activities on the one hand and different sustainability dimensions on the other hand (e.g., preserving carbon sinks of forests, mitigating damage from land-use changes and optimising environmental co-benefits of biomass production).
- The availability and cost-efficiency of **alternative defossilisation options** for different potential end-uses of biomass.
- The potential of biomass to **contribute to negative emissions** through long-term storage in materials or via Biogenic Carbon Capture and Storage (BioCCS).

Biomass resources and trade-offs

As a basis for our scenario, we compare benefits and drawbacks of different biomass uses. Biomass is a finite resource and its production, mobilisation and use have environmental and other external effects, such as on soil health, water resources, biodiversity, carbon cycles and rural livelihoods.

An increasing use of biomass has two potentially significant limitations:

- Additional wood harvesting has negative impacts on the forest carbon sink and potentially other

forest ecosystem services, depending on harvesting intensity and implementation (Chapter 4.7).
- Biomass production on agricultural land incurs opportunity costs of land because land is finite. Land used for biomass production could otherwise be used for other purposes, such as growing food and feed, expanding forests or restoring nature. Increasing the overall demand for biomass affects market balances for agricultural and forestry products, potentially leading to indirect land-use change (iLUC) both domestically and internationally. iLUC could reduce the effectiveness of using biomass for mitigating climate change.

Compared to today, the share of lignocellulosic biomass increases in the scenario, as it can be produced more sustainably on agricultural land than conventional annual energy crops (Chapter 4.5).

Next to optimising the production and end-use of biomass, the efficiency of material use and recycling can be enhanced.

Alternative defossilisation options

We assume that many current biomass applications will have cheaper and more climate- and land-efficient alternatives available by mid-century. This is particularly true for bulk power, heat production and the transport sector, which will be largely electrified (Energy Transition Commission 2021, Sathre & Gustavsson 2021). Solar and wind power are more land-efficient as a basis for electrification than bioenergy, which requires 50 to 100 times more land per unit of energy produced (EASAC 2022).

In the scenario, biomass is prioritised when no other, more efficient alternatives are available, such as for producing materials or aviation fuels. Consequently, the development of value chains that are currently non-existent or marginal is important for the sustainable use of biomass. In the chemical industry, for example, investment in biorefineries would provide technologies for processing biomass into raw materials for biochemicals (Agora Industry 2023). The increasing share of woody biomass used for materials complies with the cascade principle, stating that energy use should only be considered when material use is no longer efficient or feasible.

Additionally, biomass continues to be used in sectors where it is not the most climate-efficient option in the long term, due to the incomplete transition to alternatives by mid-century (e.g., decentralised heating). In many cases, however, the relative advantage of using biomass for materials or chemicals rather than energy will increase in the future. This is because fossil-based materials become more expensive when associated emissions are subject to higher carbon prices. Concrete, for example, becomes more expensive with Carbon Capture and Storage (CCS) in cement production, making it more attractive to replace it with wood in construction. In addition, the alternatives for many current applications of bioenergy will become cheaper, such as electric cars or heat pumps.

Contributions to negative emissions

The increasing need for carbon management and negative emissions in the transition towards climate neutrality affects the optimal allocation of biomass. Potential biomass uses for negative emissions are material uses, and energy uses combined with CCS or Carbon Capture and Use (CCU). Material uses are beneficial especially if the material itself has a long lifespan such as wood in buildings. Since the construction and maintenance of CCS and CCU infrastructure is costly, it will likely be limited to larger point sources (e.g., large industrial installations).

Apart from the continuation of current developments in traditional material uses (e.g., construction, packaging and paper), a driver of demand in our scenario is the replacement of fossil feedstocks with biomass alternatives in the chemical industry. Material Economics (2021) projects a demand between 190 and 310 TWh for the EU-28 (170 and 270 TWh based on own Brexit correction). This is substantially lower than other scenarios in Duscha et al. (2019) and Bazzanella & Ausfelder (2017), due to ambitious targets for recycling, substitution and demand reduction. This is because Material Economics (2021) relies on a scenario where only 33% of the demand for plastics is satisfied by bio-based plastics, while 53% are satisfied through different modes of recycling and 14% through demand reduction and alternative materials (Material Economics 2019). If these recycling rates are not met, the demand for biomass is likely to be higher.

Of the total biomass demand for energy of about 1 200 TWh in 2045, most is solid biomass with 1 000 TWh, and a smaller share is biogas or biomethane with around 200 TWh (corresponding to 20 billion cubic metres (bcm) of biomethane). Liquid biofuels are derived exclusively from solid biomass (280 TWh based on the projections from Agora Energiewende (2023)). Biofuels play a role only for certain types of transportation and machinery. Long-haul aviation relies on liquid fuels because electricity and hydrogen cannot replace it. A certain share of offroad vehicles is also projected to run on liquid biofuels or synfuels in the long run. As part of the transition, first-generation liquid biofuels derived from starch, sugars and vegetable oils will be largely phased out as their negative environmental effects outweigh the benefits (Chapter 4.2.2). However, it is conceivable that fuels for offroad vehicles, like farm machinery, will partly be produced from vegetable oils if this constitutes a competitive solution especially when based on regional value chains.

The projected bioenergy demand assumed for this study is 29% lower than the latest EU projections from the impact assessment accompanying the Communication from the European Commission on the 2040 climate target (European Commission 2024b).[22] The divergence from the European Commission's scenarios is mainly due to the lower biomass allocation for power and district heating in our scenario, as well as the exclusion of biomass use in maritime transport. Material Economics (2021) suggests that shipping can be powered by green hydrogen, as its price is predicted to be lower than the price of biofuels.

22 The value used for comparison is the sum of the final bioenergy demand by sector for the LIFE sensitivity analysis of the S3 scenario in 2050.

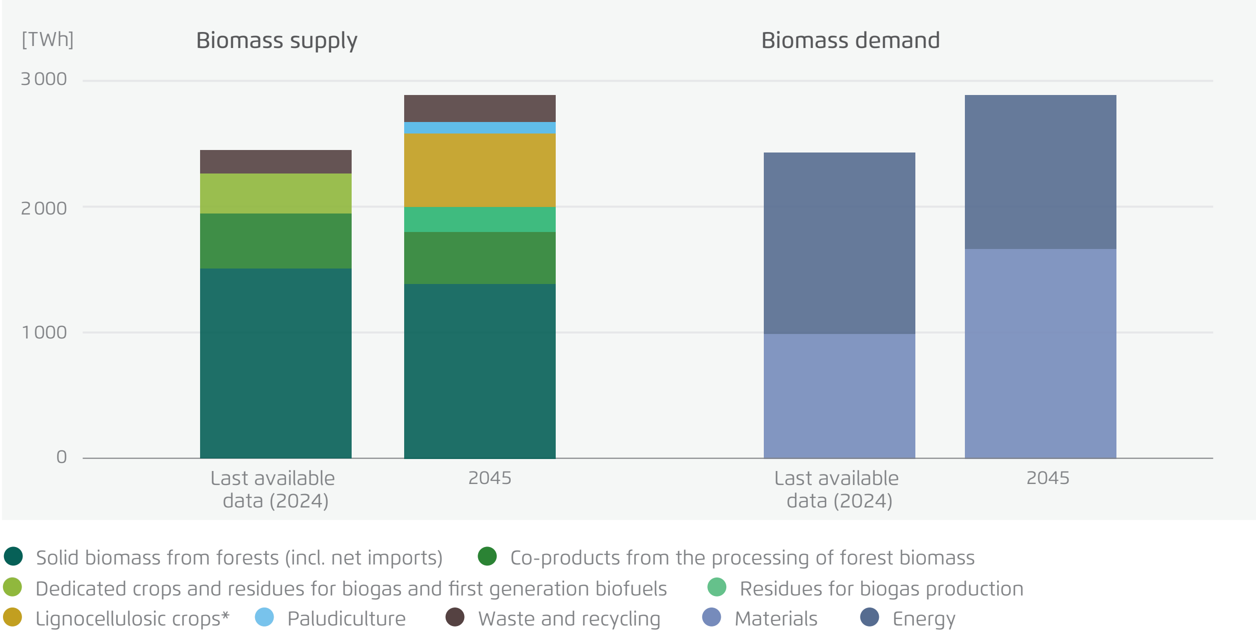
B) Establishing new supply of lignocellulosic biomass on 8% of agricultural land

The rising demand for biomass can be met by two categories of biomass: solid biomass and biomass used for biogas and biomethane production. Biogas and biomethane are produced mostly from agricultural manure, feed residues, crop residues, catch and cover crops, biowaste, sewage sludge and extensive grassland. For further details on those see Chapter 4.5. This chapter focuses on the supply of solid biomass by 2045 from the following sources:

- Forests are the primary source for solid biomass. As described in Chapter 4.7, the average forest harvest in the scenario is about 10% below today's level. Forests supply about 1 130 TWh (1 160 TWh with net imports included) of forest wood and 410 TWh of co-products.
- Paludiculture from rewetted peatlands contributes 35 to 100 TWh to biomass supply.
- Approximately 150 TWh result from paper waste and about 70 TWh from wood recovered after use (Material Economics 2021).
- Based on the demand development described in Section A, the remaining supply gap of 580 TWh of solid biomass in 2045 is met by biomass from perennial lignocellulosic crops grown on agricultural land. Lignocellulosic crops refer to a range of plants rich in cellulose, hemicelluloses and lignin, including fast-growing trees, such as willow and poplar, and energy crops like energy grasses and reeds (ESABCC 2023). They provide co-benefits like ecosystem services, carbon sink effects and increasing resilience to the impacts of climate change (Chapter 4.2.2). To meet the projected demand gap across the EU, we estimate that about 13 million hectares of lignocellulosic crops will be needed, with each hectare producing roughly 10 tonnes of dry organic matter annually.

In the scenario, renewable carbon is largely domestically supplied. However, the evolution of biomass supply from various sources will depend on factors such as the competitiveness of fast-growing trees and biomass overall. We do not analyse the potential for importing more chemicals based on biomass or Direct

Demand and supply of biomass in the bioeconomy in the EU → Fig. 9



Agora Agriculture based on Agora Energiewende (2023), Dahms et al. (2017), European Commission (2021k), Eurostat (2023h), Material Economics (2021). *e.g., short rotation coppices, agroforestry, miscanthus

Air Capture (DAC), increasing biomass supply from grasslands and agricultural residues, like maize straw (except for biogas, see Chapter 4.5), or increasing the use of waste and residues.

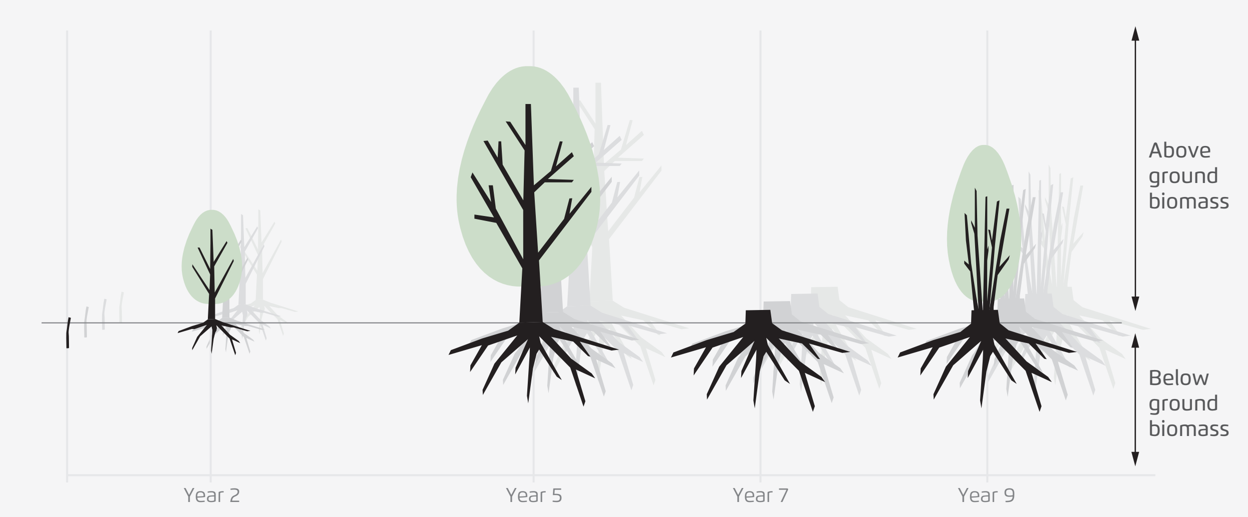
Although perennial grasses such as miscanthus could play a role, we expect fast-growing trees, like poplar and willow, to be the main source of biomass from agricultural land. In our scenario, these trees are primarily managed as Short Rotation Coppices (SRCs). The characteristic of SRCs is the resprouting from the harvested stump allowing for periodic harvest with a cycle length between around three to ten years (Figure 10). SRCs can be included in agroforestry systems. Agroforestry is a land use system that integrates trees or shrubs with arable crops or livestock farming. We use the term "fast-growing trees" to refer to the whole range of formations in which these trees can be grown, including agroforestry systems, diversified woody structures and plantations.

In general, fast-growing trees share several characteristics, including:

- High biomass yields per hectare, which can decrease indirect land-use changes.
- Low input intensity, therefore contributing to reduced use of plant protection products and nitrogen surplus at the landscape level.
- Various ecological co-benefits, including carbon sequestration.
- Low site condition requirements, making them adaptable to a range of environments.
- Versatility in use, suitable for diverse material applications as well as heat energy production.

The distribution of the projected area used to produce lignocellulosic biomass among member states and regions across the EU depends on numerous factors. This includes the local demand and price of biomass, transport infrastructure, regional land rent trends, agro-ecological conditions, the development and distribution of new value chains, as well as the potential co-benefits for neighbouring crops and pioneering farm managers. In any case, the size of the projected areas in our scenario has the potential to reshape landscapes. Therefore, it is important to consider the landscape-level effects of cultivating fast-growing trees on agricultural land.

Illustration of short rotation coppices over time → Fig. 10



Agora Agriculture

In our scenario, we assume that fast-growing trees are managed to deliver more ecological co-benefits compared to the current EU land use system. These benefits include increased biodiversity, an additional carbon sink and improved climate adaptation, increased soil health and water and air quality (Chapter 4.2.2). These co-benefits are maximised when fast-growing trees are incorporated into agroforestry systems or integrated into the broader landscape on non-agricultural land. These woody structures can be counted towards the area of semi-natural landscape features as defined in this study (Chapter 4.5.1). In this way, synergies can be realised between the production of biomass and other land services such as carbon removals and enhancing biodiversity.

In our scenario, we project that fast-growing trees will be competitive with other field crops and will not remain a niche crop. Although we do not analyse the specific growing conditions that would enhance this competitiveness in detail, we base the spatial distribution on the following criteria:

- Negative effects of fast-growing trees can occur if tree cover increases in excess, potentially threatening species that rely on open landscapes for their food sources (Finck et al. 2002). Therefore, we restrict the tree cover area composed of forests and fast-growing trees on agricultural land to 50% of the total area per NUTS-2 region, leading to the exclusion of 50 out of 215 EU regions from extending the production of lignocellulosic biomass on agricultural land.
- Co-benefits may be reduced if precipitation levels are too low. For example, in areas where annual rainfall is lower than 500 mm per year, large-scale cultivation of fast-growing trees can reduce groundwater levels. In these conditions, fast-growing trees may also compete with other crops (Rödl 2017). Good growing conditions require a precipitation level of more than 300 mm during the growing season (von Behr et al. 2012). To address this requirement, we exclude 30 regions with annual precipitation below 300 mm from the allocation of perennial crops.
- Although we project that fast-growing trees will be a profitable land use option by 2045, they also offer the advantage of thriving on marginal lands, making them valuable even in less favourable conditions. We anticipate that fast-growing trees are also grown in areas where other agricultural crops may become unprofitable in the future due to poor soil quality and the impacts of climate change. Estimates of the total area of this type of land vary. An analysis by Perpiña Castillo et al. (2021) projects that there could be 5.6 million hectares of abandoned land in the EU and the UK by 2030. However, the suitability of this area for cultivating

fast-growing trees remains uncertain. We consider the integration of marginal lands into our scenario by preferentially allocating fast-growing trees on land that would otherwise be fallowed in the CAPRI model analysis.

Further details about the specific spatial allocation and the model analysis can be found in Annex Chapter 3.

4.2.2 Environmental and climate impacts

The biomass supply outlined in our scenario provides ecological benefits that exceed those of current biomass production systems. Transitioning from annual crops used for biogas or first-generation biofuels to fast-growing trees for material and bioenergy use offers significant environmental benefits. These advantages include enhanced carbon sequestration, improved climate adaptation, biodiversity and reduced soil erosion. At the same time, the negative effects of the current production of annual energy crops are reduced.

The cultivation of fast-growing trees sequesters carbon from the atmosphere. Compared to annual crops, perennial lignocellulosic crops have a longer harvest cycle and therefore bind more carbon in the aboveground and belowground biomass. Their root system also represents a longer-term carbon sink because there is no removal of the root systems if the tree production system remains in place. To illustrate the carbon sequestration benefits, we estimate the net carbon sink from cultivating fast-growing trees on 12.7 million hectares for solid biomass production in our scenario.

About 12 million hectares of fast-growing trees are established on arable land and 0.7 million hectares on grassland, both assumed with a linear development between 2025 and 2045. In total, this results in an additional carbon sink of about 660 million tonnes of CO_2 equivalent ($MtCO_2eq$) in the period 2025–2045, or around 30 $MtCO_2eq$ on average per year, if the harvest cycle is seven years. Each hectare of fast-growing trees sequesters between 47 and 52 tonnes of CO_2 equivalent in aboveground biomass, and between 14 and 19 tonnes in belowground biomass during the establishment phase. The carbon sequestration strongly depends on the length of the harvest cycle, with shorter harvest cycles leading to a comparatively lower carbon sequestration effect. Details can be found in Annex Chapter 3.

Furthermore, the use of the harvested biomass can have positive climate effects in two ways:

- Woody biomass can substitute fossil-based feedstocks or carbon-intensive products.
- Carbon from the woody biomass can be stored in products such as glued laminated timber, plastics or other materials. Those products can bind carbon for longer periods of time if they are well designed, used and recycled.

With the projected yield of 10.2 tonnes of dry matter per hectares and year, corresponding to 5.1 tonnes of carbon, 65 million tonnes of renewable carbon are provided to other sectors each year from 2045 on. Before mid-century, lignocellulosic crops are phased in, resulting in a proportionately lower amount of carbon sequestration. The climate change mitigation effect of this biomass is reflected in the substitution factor, which depends on the substituted material or the energy mix and its greenhouse gas intensity. We assume that the substitution factor is at least 0.55, which is the factor for wood replacing natural gas for heat production in industry, based on the calculation by Leturcq (2020) using IPCC default values. This means that at least 131 $MtCO_2$ emissions could be mitigated annually in our scenario through using the wood from fast-growing trees.

In addition to the climate change mitigation potential, woody structures in the agriculture landscape have other important benefits, even though they are not quantified in our scenario.

The expansion of fast-growing trees can contribute to climate adaptation in agriculture. When well-integrated into the landscape, woody structures increase resilience to the impacts of climate change such as heat stress and drought. They help by shading the soil, reducing wind speed and creating microclimates that mitigate water evaporation from the soil (Brandle et al. 2004). The climate adaptation potential largely depends on their design within the landscape and the natural site conditions. For example, if the tree density is too high, competition for water can outweigh the benefits of the microclimate created (Ivezić et al. 2021). The shading effect can also have a negative effect on the crop yield due to competition for sunlight. This is particularly true for central and northern European locations with comparatively low solar-radiation intensity (van der Werf et al. 2007). In dry conditions and on poor soils, the presence of integrated trees can even enhance the yield of annual crops. This is due to the creation of beneficial microclimates and the addition of tree litter, which improves soil quality (Jose 2009).

Another benefit of fast-growing trees is the prevention of soil erosion. A large part of the EU arable land is affected by soil erosion (Borrelli et al. 2023). The risk of erosion is projected to increase due to extreme weather events as a result of climate change (Panagos et al. 2021). Fast-growing trees can help mitigate soil erosion in agricultural landscapes. Trees in these systems slow down wind, enhance soil cover, reduce the length of slopes, capture eroded sediment and increase water infiltration in the soil (Seobi et al. 2005, Zehlius-Eckert et al. 2020).

The cultivation of fast-growing trees can also contribute to biodiversity in agricultural landscapes (Vanbeveren & Ceulemans 2019). This is because these production systems have a longer crop rotation with fewer disturbances during the growing period, support greater spatial diversity and offer improved soil protection. In addition, these systems require lower amounts of fertiliser and plant protection products (Rowe et al. 2009). The effect depends on the structural heterogeneity of the surrounding landscape (Chapter 4.5.1). Especially in agricultural landscapes with few semi-natural landscape features, fast-growing trees provide valuable habitats and represent a strong ecological contrast (Dauber et al. 2010). If the production system is designed as an agroforestry system, the benefits to biodiversity can be even greater. The higher the edge density of the agroforestry system, the more valuable it becomes for biodiversity. In agroforestry systems, a higher edge density creates more boundaries between tree areas and open agricultural land, which creates a variety of habitats. Accordingly, strip-shaped agroforestry systems have a higher biodiversity value than large patches (Vanbeveren & Ceulemans 2019).

Another positive effect of fast-growing trees for biodiversity is the reduced usage of plant protection products and fertilisers. This lowers the emissions of synthetic chemicals and their metabolites into the environment and lowers nitrogen emissions in the form of nitrate (NO_3^-), ammonia (NH_3) and nitrous oxide (N_2O), thus contributing to groundwater protection, air-pollution control and climate change mitigation (Ding et al. 2021). In our scenario, we achieve a 31% reduction in the total amount of managed nitrogen (i.e., synthetic fertilisers, manure and other sources) and a 52% decrease in the use of plant protection products. Of the reduction in nitrogen input, 59% can be attributed to lower fertilisation of arable crops, grassland and rewetted areas and 15% to the decrease in agricultural land. The remaining 26% are linked to the establishment of fast-growing trees without additional nitrogen inputs. Likewise, these trees, which are grown without the use of plant protection products in our scenario, account for 16% of the reduction in plant protection products use.

To assess the impact of dedicating 8% of agricultural land to fast-growing trees on EU agricultural production and trade balances, we conducted a sensitivity analysis comparing our scenario with and without these trees. Without these trees, annual crops would be cultivated on a substantially larger area (+11.2 million hectares) but have lower yields than in the main scenario due to constraints on nitrogen surplus and plant protection product limits as well as price effects, which affect the entire area of annual crops. For example, while an additional 6.5 million hectares would be allocated to cereals, grain production would only increase by 18 million tonnes, and EU net exports would increase by only 12 million tonnes. Innovations in breeding and application technologies for plant protection products and nutrients may, however, allow a reduced use of these inputs without affecting yields as much as in our analysis. In such a case the increase in cereal production would be stronger. Furthermore, agricultural greenhouse gas emissions outside the EU would decrease by only 4 million tonnes if fast-growing trees were not established in the EU. These results suggest that lignocellulosic crops can be an efficient land use alternative, especially when environmental constraints require lowering plant protection products and nitrogen surplus.[23]

Finally, the development of fast-growing trees and the increasing use of waste and residues for bioenergy can reduce the impacts of crop production currently used to produce biogas and biofuels from starch, sugar and oil.

4.2.3 Socio-economic impacts

The cultivation of perennial lignocellulosic crops, particularly fast-growing trees, presents economic opportunities for land users but also entails challenges.

Overall, we expect fast-growing trees to be a viable additional income opportunity for farmers in 2045. Given the current market prices of wood and energy, these trees are less competitive compared to annual crops in many countries and regions. While future prices of biomass and potential revenues from its production are difficult to predict, there are several reasons to believe that fast-growing trees will become profitable in the coming decades:

- We have adopted a high-value scenario where biomass is reserved for uses without more efficient defossilisation options. In such a situation, the carbon price and the substitution effect will determine the willingness to pay for biomass. In our scenario, fast-growing trees produce 10.2 tonnes of dry matter and 5.1 tonnes of carbon per hectare annually. Applying a substitution factor of 0.55 (Chapter 4.2.2), an annual 10.3 tonnes of CO_2 emissions can be mitigated by one hectare of lignocellulosic biomass. Assuming a carbon price of 200 euro per tonne, this carbon would be worth 2 060 euro, which can be interpreted as the maximum willingness to pay on top of the price of the alternative fossil product for the biomass harvested per hectare and year.
- As outlined in Chapter 4.2.2, growing trees on agricultural land constitutes a carbon farming activity that can generate additional income in the establishment phase due to storing carbon in the root system, for example.
- In addition to an increase in the price for lignocellulosic biomass, we assume production and marketing costs to decline by 2045. This is due to economies of scale driven by greater biomass availability, increased competition among service providers for planting, harvesting and aggregation, as well as improved extension networks and increased investment in research and development.
- Lastly, we expect that the competitiveness of lignocellulosic relative to annual crops will improve, as they offer farmers significant savings on the use of plant protection products and fertilisers, which facilitates compliance with environmental regulations.

Furthermore, the cultivation of fast-growing trees presents an opportunity for income stabilisation. On the one hand, the inclusion of trees in the production mix of a farm is a direct diversification of income sources. Securing long-term contracts with wood buyers could provide farmers with a stable and reliable income source. Also, as stated above, agroforestry systems can improve the resilience of agricultural systems against climate change (Ivezić et al. 2021). Another economic advantage of agroforestry systems compared to large-scale plantations is that fast-growing trees have higher yields, reducing the overall land requirement (Böhm et al. 2020, Kanzler et al. 2019).

In the scenario, fast-growing trees expand from marginal levels to about 8% of the agricultural area. Value chains, markets and contractual arrangements still must be developed. Since this process is

23 Quantitative results derived from a sensitivity analysis conducted in CAPRI.

expected to be completed by 2045, the steep growth curve implies that many farmers will need to take on pioneering roles during the transitional period. Managing the associated uncertainties will be challenging. The expansion of fast-growing trees will require substantial upfront investment and result in a temporary reduction in regular annual income. In Germany, for example, the initial investment for implementing fast-growing trees is around 3 000 to 4 000 euro per hectare. Especially with longer rotations, which are desirable from an environmental point of view, revenues will start only after seven or more years, potentially translating into a lack of financial liquidity for the prior period (Ford et al. 2024). This hurdle could be overcome by public or private payments to remunerate the services of carbon removal and biodiversity preservation through woody structures in the agricultural landscape (Section B in Chapter 4.2.4).

The upfront investment and the perennial nature of the crop also imply a long commitment period of 20 years or more. Apart from the liquidity challenge mentioned above, this presents a risk factor for the farmer, particularly in the absence of long-term contracts with buyers (Finger 2016, Hauk et al. 2014).

Finally, because the land use is fixed for about 20 years, landowners (in case of rented land) also need to be convinced. Rental contracts for land need to align with the investment cycle. If there is legal uncertainty regarding the reversibility of the fast-growing trees or agroforestry systems, this may be a barrier for landowners' consent to the establishment of trees on their property.

4.2.4 Policy options

Compared to today, our scenario suggests strong changes in supply and demand patterns for biomass by 2045. These patterns will not materialise within the current policy framework. For example, the EEA (2023d: 127) projects "a growing gap from now to 2050 between policy-driven biomass demand and biomass availability for bioenergy and bio-based materials".

A key factor determining biomass use is the interplay between climate and renewable energy policies. Currently, these policies often incentivise biomass demand in a fragmented way, overlooking the broader agricultural and Land Use, Land-Use Change and Forestry (LULUCF) greenhouse gas impacts and failing to account for alternative biomass uses. Therefore, a comprehensive EU action plan for biomass in the bioeconomy is needed to improve the coherence of EU policies. Such an action plan would address the interactions between the food system and the bioeconomy, offering a roadmap to align key EU policies with goals for a climate- and land use-efficient biomass utilisation and increased carbon removal (Chapter 5.4).

As described in this chapter, efficient biomass use demands measures to redirect biomass from bioenergy applications to material use. On the supply side, measures are needed to complement forests-derived woody biomass with lignocellulosic crops, particularly fast-growing trees on agricultural land.

In this section, we provide an outlook on how EU policies could better contribute to steering the demand and supply of biomass towards efficient and more sustainable options:

A) Align policy incentives for biomass uses with their environmental effects
B) Support the development of lignocellulosic crops

A) Align policy incentives for biomass uses with their environmental effects

As part of our scenario, we envisage two major changes in the use of biomass in a climate neutral economy. First, there will be a reduction in bioenergy consumption, particularly in low-temperature heat, bulk power and transportation, with only a small growth in industry applications. Second, we project a strong increase in biomass use for material purposes.

In theory, an optimal allocation of biomass is reached when the same carbon price is applied in all sectors, including the LULUCF sector (Merfort et al. 2023), and when other environmental impacts are reflected in biomass prices. This would result in a relative shift from forest wood to wood from SRCs. As highlighted in Chapter 4.7, we suggest that the impacts of harvesting forest wood on the carbon stock and sink in forests are accounted for, such as through differentiated pricing of emissions from forest wood.

In contrast to forests, emissions from burning biomass sourced from agricultural land are less critical because the carbon sequestered by these crops is captured over a relatively short period. However, the direct or indirect Land-Use Change (dLUC and iLUC) associated with biomass production can have significant negative effects on the climate and biodiversity. Land-use change is particularly concerning when it occurs at the expense of carbon-rich natural or semi-natural ecosystems, such as tropical rainforests or savannas. The severity of the land-use change problem depends on the scale of biomass production and the types of crops used. In addition, it is important to consider the impacts on other sustainability dimensions of various biomass production systems. To address these issues, the following categories of measures can help guide the system into the right direction:

- Adjusting incentives and targets for biomass use to account for **land use impacts** and the sustainable supply potential of different types of agricultural biomass.
- Incentivising material use of biomass that provide **long-term carbon storage** and replace fossil carbon in materials.

Factoring in land use effects

Land-use change needs to be better reflected in the incentives for biomass use. In current legislation on biofuels for transport, certain provisions aim at reducing negative land-use change effects. For dLUC, current regulations prohibit biofuels sourced from land converted from high-carbon stock areas since 2008. These criteria are relatively strict compared to other biomass uses and can serve as a model for sustainability criteria for other sectors. However, the absence of iLUC factors in their calculations likely leads to overestimated greenhouse gas emissions savings (ECA 2023b). Instead, the EU has adopted a risk-based approach through the Commission Delegated Regulation (EU) 2019/807, which classifies biofuels as having high or low iLUC-risk. So far, only palm oil has been classified as a high iLUC-risk feedstock for biofuels according to the current criteria. There are no similar sustainability safeguards for biomass uses outside the transport sector, such as for biogas in the recently adopted EU Hydrogen and Decarbonised Gas Package (Regulation (EU) 2024/1789 and Directive (EU) 2024/1788).

While phasing out the most problematic feedstocks is a step in the right direction, the current approach still has fundamental limitations. Regulation (EU) 2019/807 evaluates each crop in isolation and considers it acceptable as long as there is no significant global expansion of that crop. However, this approach overlooks indirect effects. For example, the increased use of rapeseed oil for biofuels has likely led to the substitution of rapeseed oil with palm oil in other applications (Baral & Malins 2016). Furthermore, these rules do not apply to crops used as biogas feedstock or in other sectors beyond biofuels and bioliquids.

This evidence calls for a comprehensive, cross-sectoral approach for biofuel feedstocks. Such an approach should consider the demand for arable land needed to produce different biofuel feedstocks and address the resulting land-use changes (Millinger et al. 2018, Searchinger et al. 2022). There are different ways to improve current legislation to better reflect the land use impacts of biofuels.

Ideally, the net greenhouse gas emissions from iLUC associated with the use of different biofuel feedstocks and energy crops would be directly included in the calculation of greenhouse gas emissions savings. Indirect land-use change can be assessed only through economic and land use modelling. As part of such an approach, it is crucial to regularly update the modelling analyses to reflect changes in markets and land use. Abandoning renewable mandates in favour of greenhouse gas emissions savings targets, as some member states have done in their biofuel policies, could make renewable energy use more efficient and effective for greenhouse gas mitigation (Christensen 2021).

Alternatively, the current regulatory approach based on iLUC risk can be strengthened. For example, the current method for assessing the risk of iLUC could be replaced by regular model analyses reflecting a more comprehensive range of pathways, through which demand for biofuels can affect land-use change. In the very short term, an adjustment of the threshold for expansion into high-carbon stock area could help lower the use of further feedstocks with a high iLUC risk, such as soybean oil. In the medium term, the phase-out of all first-generation crop-based biofuels could follow. Both approaches would incentivise more sustainable biofuels (according to Annex IX of the Renewable Energy Directive ((EU) 2018/2001) like biofuels from lignocellulosic crops or from waste and residues, which are less land-demanding than conventional biofuels.

Complementary to stronger regulation and better accounting, renewable targets need to reflect the overall sustainable supply potential and the different value of biomass for the defossilisation of various sectors. Renewable targets for road transportation could be adjusted to levels that eliminate the need for first-generation biofuels. Instead, efforts should focus on accelerating the electrification of road transport, which currently is already a more efficient alternative.

Another important example is the biomethane target of 35 bcm for 2030 proposed through the REPowerEU plan (European Commission 2022d). Although member states have not endorsed this target as part of the Gas and Hydrogen Markets Regulation ((EU) 2024/1789), it continues to shape the policy context. As biogas production can be a valuable contribution to greenhouse gas mitigation in manure management as well as nutrient cycling at farm-level, clear targets are key to provide planning and investment security to producers. However, it is crucial to set the target based on a scientific assessment of the sustainable supply potential to avoid incentivising the continued large-scale production of dedicated biogas crops, such as maize. The target of 196 TWh we apply in our scenario corresponds to 19.6 bcm of biomethane. Based on Abdalla et al. (2022) this is the order of magnitude that can realistically be supplied from waste and residues. The 35 bcm target would be associated with an inefficient expansion of maize production for biogas and go beyond the demand scenario from Agora Energiewende (2023).

Longer-term carbon storage

Incentives also need to better reflect the benefits of different biomass uses. Storing renewable carbon in long-lived products or products with many recycling cycles, such as construction materials or plastics, has the potential to create temporary carbon sinks and presents an opportunity to partly replace fossil carbon. Unlike for bioenergy, a larger framework to incentivise the use of bio-based or recycled carbon for materials is still absent. The cascade principle for wood, defined in the EU Renewable Energy Directive, does not lead to the desired effect.

For chemical products, for example, the largest share of emissions occurs when products drop out of the recycling cycle and are incinerated (Agora Industry 2023). Pricing emissions in the waste sector, however, does not provide a signal to substitute fossil carbon with biogenic carbon in materials and chemicals, as the traceability until the end of life is difficult to achieve. Therefore, other instruments need to be put in place. One option could be to levy a climate surcharge on end products containing plastics, which can be used to finance the uptake of renewable carbon in the chemical sector and other industries. Alternatively, a surcharge could be imposed on fossil feedstocks at the point of entry, reflecting their carbon content and thereby increasing the demand for bio-based alternatives. Other approaches that consider the full life cycle emissions and carbon content of products would require a solid methodology to monitor the carbon bound in chemicals and other materials. This monitoring system must account for exported plastics and other chemical products. Once the greenhouse gas balance of this system is fully assessed, certifying some renewable carbon uses as temporary removals may be a viable option. However, it is key that the rules under the EU Carbon Removals and Carbon Farming (CRCF) Regulation adequately reflect the temporary nature of these products. This can provide the basis for the chemical and other industries to participate in voluntary carbon markets. The inclusion of these temporary removals into an Emissions Trading System (ETS) requires further careful considerations, which are not elaborated here.

An array of policy measures is available to stimulate the replacement of fossil carbon by bio-based and other renewable alternatives. The Ecodesign for Sustainable Products Regulation ((EU) 2024/1781) and its Delegated Acts establish a unified methodology for assessing the environmental and carbon footprint of various products. This framework provides a foundation to require producers of chemicals and other products to enhance their environmental performance. Instruments such as bio-based content quotas or embedded carbon limits can be used to reduce fossil carbon in chemicals and materials.

B) Support the development of lignocellulosic crops

As outlined above, we assume a growing demand for biomass from lignocellulosic crops through a combination of market developments and political framework conditions targeting the use of biomass. Rewards for positive ecosystem services provided by fast-growing trees would support their expansion in the form of diversified woody structures in agricultural landscapes.

In our scenario, the establishment of fast-growing trees provides a substantial amount of carbon sequestration in natural systems. It is desirable that farmers are encouraged to establish those crops by paying them for the carbon sequestration and other ecosystem services provided by woody structures. These payments can help address the long payback period and liquidity problems associated with tree cultivation. Possible avenues for remuneration include support measures under the Common Agricultural Policy (CAP), revenues from an ETS, or through voluntary carbon markets. These options are described below.

The CAP can play a strong role in funding the cultivation of fast-growing trees. Already today, agroforestry systems can be, and are, promoted in member states through the CAP. More than 25 measures are designed across member states to enhance the considered agroforestry practices, such as silvopastoral (integration of trees and grazing livestock) and silvoarable (integration of trees with arable crops) systems, forest farming, riparian buffer strips and home gardens. The complexity of implementation discourages farmers from adopting agroforestry practices. To improve uptake of these systems, the rules for implementing agroforestry should be better aligned. Additionally, ETS revenues could serve as an alternative source of funding for land-based carbon removals, provided that such funding does not undermine overall emissions reductions goals by allowing emissions to be offset through non-permanent land-based removals (Chapter 5.1).

To harness the synergy between production and biodiversity protection, the future CAP must ensure that productive woody structures are recognised as fulfilling agri-environmental obligations. As outlined in Chapter 4.5, to achieve a share of 20% of semi-natural habitats in agricultural landscapes, about 5% of EU arable land must integrate semi-natural landscape features. We assume 1.3 million hectares of semi-natural landscape features are provided with productive diversified woody structures. A future CAP could define concrete criteria for these synergetic landscape elements.

Voluntary carbon markets can also support the cultivation of fast-growing trees. Voluntary carbon markets are platforms where greenhouse gas emitters can voluntarily buy carbon credits or certificates from actors that have reduced emissions or created removals (Chapters 4.6.4, 4.7.4 and 5.1). Farmers who have planted lignocellulosic crops can certify their carbon removals and sell the corresponding certificates to companies, which use them to reach their corporate sustainability targets.

The Carbon Removals and Carbon Farming (CRCF) Regulation has created an EU framework aimed at generating standardised certificates that companies can use in voluntary carbon markets. This will allow farmers to generate and sell carbon certificates to produce fast-growing trees. The Green Claims Directive (2023/0085(COD)), currently still under negotiation, is expected to provide rules for using environmental claims. The CRCF in combination with the Green Claims Directive offers a chance to strengthen land-based carbon removals within the EU, rather than in third countries. The reliability of domestic removal activities will depend on the certification methodologies and robustness of Monitoring, Reporting and Verification (MRV) systems.

Furthermore, the CRCF could set different standards depending on the contribution to biodiversity and other co-benefits. This would create market differentiation for carbon removals based on quality, ideally driving a race to the top in terms of standards and greater co-benefits. Besides offering substantial co-benefits, carbon sequestration in fast-growing tree production systems is less susceptible to non-management induced reversals, such as those caused by higher temperatures, compared to other methods like soil organic carbon buildup on arable land. Therefore, these systems could be categorised in a "high-quality" segment of CRCF certificates.

To enhance the adoption of fast-growing trees, it is essential to advance this production model beyond its current infancy and assess the potential for economies of scale across most EU regions. The sector could benefit from a kick-start funding scheme to overcome the infancy stage, incentivising the development and scaling of upstream sectors and supporting services. This could include accelerated breeding programmes, the development of machinery and increased access to advisory services.

Finally, the limited knowledge transfer between farmers and research institutions is frequently cited as a barrier to adopting fast-growing tree cultivation (Mosquera-Losada et al. 2023). Fostering knowledge transfer through advisory services and collaboration between interested farmers appears necessary, as expertise on fast-growing trees is not yet widespread among EU farmers (Chapter 4.5.3).

4.3 Food demand

4.3.1 Scenario

Healthy and sustainable diets are important for achieving national and international sustainability objectives in health, poverty reduction, climate change mitigation, biodiversity and other environmental dimensions (Chapters 3.1, 3.3 and 3.4). As part of our scenario, the average EU food consumption patterns meet nutritional needs, reduce diet-related diseases and contribute to other sustainability objectives, such as climate neutrality and biodiversity protection. We envision food environments that enable healthy, environmentally sustainable and culturally appropriate food choices for all consumers in the EU. A strong reduction in food waste is another key element of our scenario. As a result, less agricultural land is needed to satisfy EU food demand, indirectly contributing to global food security.

For our assumptions on the average consumption of different food groups in the middle of the century, we combine data on current consumption, results of the EAT-Lancet Commission and its Planetary Health Diet[24] (Willett et al. 2019) and other studies and dietary guidelines for healthy diets with reduced environmental impacts (Blomhoff et al. 2023, European Commission 2023e, Ministry of Food, Agriculture and Fisheries of Denmark 2021, Schäfer et al. 2024, WHO European Region 2023). We account for current consumption patterns[25] and assume an average food calorie intake of 2 140 kilocalories per capita in EU member states (Annex Chapter 4). Average consumption patterns are defined for general

24 The Planetary Health Diet examines the shares of various food groups to fulfil the dietary requirements of a growing global population of 10 billion people by 2050. It aims to balance healthy diets within the limits of planetary boundaries.

25 We assume an average of 80% of the Planetary Health Diet and 20% of current consumption patterns of EU member states.

food groups such as fruits and vegetables, dairy and cereals. These broad food groups permit a wide array of combinations and choices of specific foods, ensuring that cultural and personal preferences, individual dietary requirements and culinary practices can be accommodated.[26]

The scenario on food demand includes the following elements:

A) Increasing the consumption of plant-based foods in relation to animal-based foods
B) Reducing food loss and waste
C) Creating fair food environments

This chapter describes the relevance of each of these elements, as well as the potential environmental, health and socio-economic impacts.

In Chapter 4.3.4 we discuss EU policy options to incentivise and support the changes outlined in the scenario.

A) Increasing plant-based foods in relation to animal-based foods

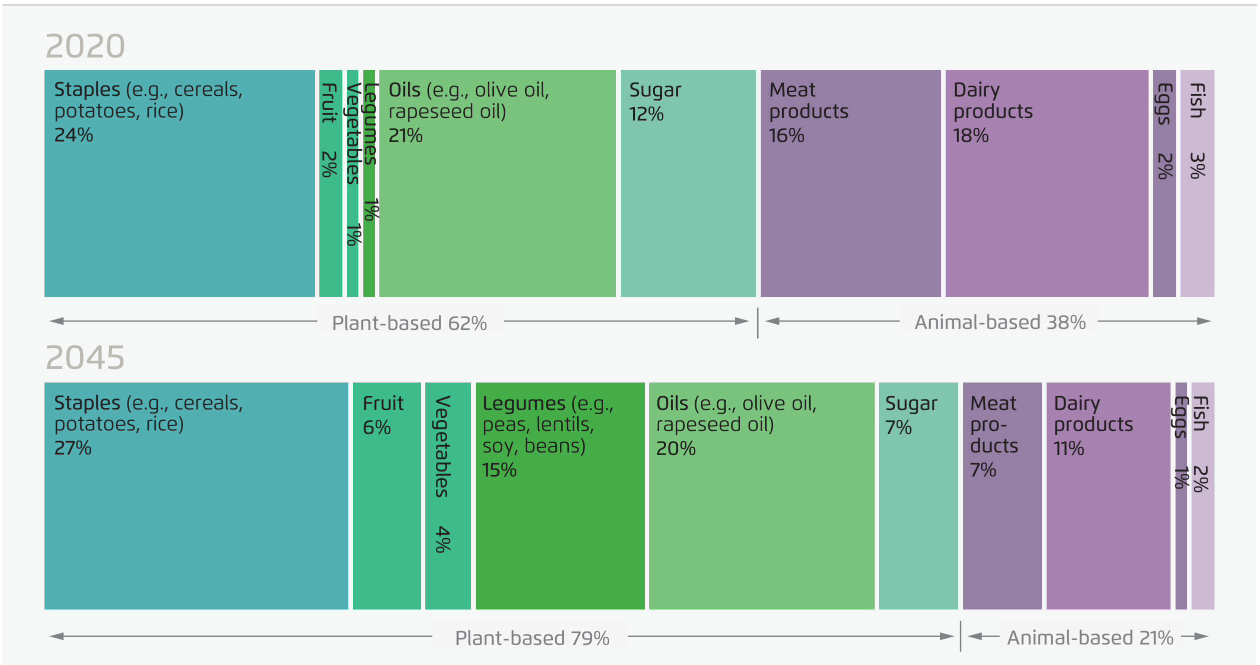
The core element of our scenario is a shift towards plant-rich diets, high in vegetables, fruits, whole grains, nuts and legumes, with moderate amounts of fish, dairy products, meat[27] and sugar (Figure 11).

The reduction in the average consumption of all meat types results in an annual average reduction of 3% per capita and a total reduction of about 51% by mid-century compared to 2020 (Table 1). Average food consumption patterns in the scenario contain not only less meat and dairy products, but

26 In our analysis, we provide an average consumption of different food groups in the EU and illustrate a consumption shift at the population level. We do not present dietary guidelines for individuals. Dietary needs vary across different population groups based on physical activity, age, sex, special dietary needs and preferences.

27 The high level of animal product consumption is a common issue in high-income countries. However, many people in low-income countries may need to increase their consumption of meat, eggs and milk to address nutritional needs, especially for the most vulnerable groups (FAO 2023a).

Calorie shares of food groups in average EU food consumption in 2020 and 2045 → Fig. 11



Agora Agriculture based on CAPRI results

also a different composition of meat types. For example, while beef is the largest contributor to greenhouse gas emissions per unit of product, it can be linked to dairy production and extensive grazing. This linkage presents an opportunity to utilise and maintain grasslands, thereby protecting biodiverse habitats. Based on these considerations, beef consumption decreases by approximately 60% (or 3.6% per year). Pig meat consumption decreases by 67% (or 4.3% per year), while poultry-meat consumption decreases to a lesser extent (by 18% or 0.8% per year) due to higher feed efficiency and current positive consumption trend (European Commission 2023l). For information on how changes in consumption patterns impact livestock production, see Chapter 4.4.

An increase in the consumption of fruits, vegetables, legumes and nuts contributes to a sufficient intake of protein and nutrients. The consumption of fruits and vegetables more than doubles (by about 150%, or by 4% per year), while the consumption of legumes increases roughly tenfold, albeit from a very low starting point. Legumes are important for delivering protein and can provide the basis for plant-based alternatives to animal products.

In our scenario, the share of plant-based proteins in grams/day/person increases from 30% to 62%, mirrored by a decline in animal-based proteins from 70% to 38%, as Figure 12 illustrates. In total, more protein will be available for human consumption per capita in the EU in 2045 compared to 2020 (Figure 12). The supply is thus sufficient, even when considering the lower bioavailability of plant proteins compared to animal proteins.

The future EU food market will be increasingly influenced by alternatives to animal products, such as those from precision fermentation or cell cultivation. These can contribute towards the diversification of protein in food or in ingredients for food and feed (EIT FOOD 2022, FAO 2021, IPCC 2019, UNEP 2020a). For our scenario, we acknowledge the growing relevance of alternative proteins (Infobox 2 and Chapter 4.3.4) without analysing future market shares, production methods, or impacts on sustainability and the agricultural and food sectors.

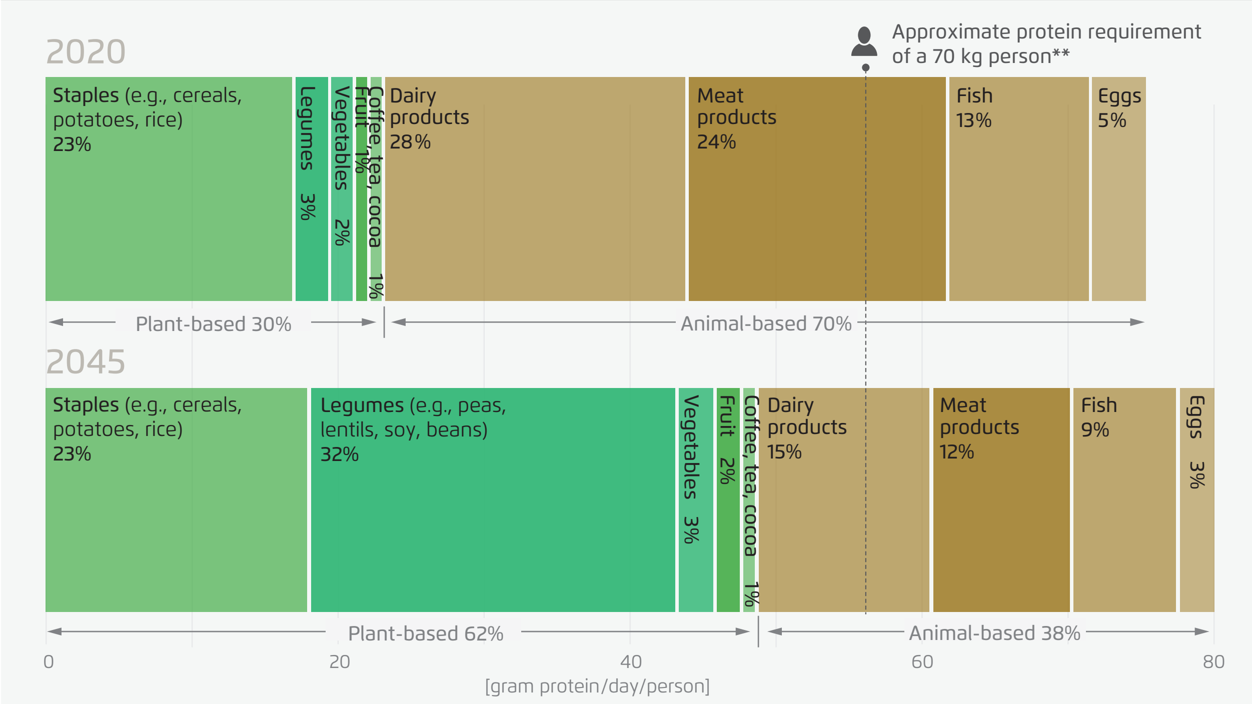
Changes in per capita intake per food group

→ Table 1

Food groups	2020 intake (grams/day/person)	2045 intake (grams/day/person)	Annual change (%)	Total change 2020–2045 (%)
Meat	147	73	-2.8	-51
Dairy (milk eq)	641	367	-2.2	-43
Sugar	69	39	-2.2	-43
Eggs	28	16	-2.1	-42
Fish	52	37	-1.4	-30
Oils	54	48	-0.4	-10
Cereals and rice	147	154	0.2	5
Potatoes	71	78	0.4	10
Fruits	89	219	3.7	147
Vegetables	119	298	3.7	151
Legumes (peas, soy, beans and lentils)	8	90	10.4	1 076

Agora Agriculture based on CAPRI results

Protein content of average EU food consumption* in 2020 and 2045 → Fig. 12



Agora Agriculture. * gram per day per person; ** Walpole et al. (2012)

Infobox 2: Alternative proteins

Alternative proteins can substitute for a wide range of products such as meat, seafood, eggs and dairy. While there is no clear or legally set definition of alternative proteins, they can be broadly categorised into plant-based alternatives, cultured meat and dairy products, fermentation-derived microbial proteins (including algae- and fungi-based proteins) and insect-based proteins. Within the debate, "alternative proteins" is also used as a broader term, including both the protein and fat components.

Alternative proteins differ in terms of technological maturity and current market shares. For example, while cell-cultured meat awaits regulatory approval for its introduction to the EU market, plant-based milk already accounted for 11% of total fresh milk sales in 2022 in 12 EU countries and the UK (Battle et al. 2022). Meat alternatives are likely to remain largely plant-based until 2030.

After that, the long-term market developments of alternatives to animal products are uncertain and depend on factors such as the speed and scaling of technological innovations, consumer demand and acceptance, investment and regulatory approval (Markets and Markets 2021). Limited scientific evidence is available to assess the sustainability impacts of some of those alternative products and technologies. While there is already a growing body of analyses that estimate substantial environmental benefits from plant-based alternatives, there is not yet sufficient data to estimate the environmental impacts for cell-cultured meat and precision fermentation (Humpenöder et al. 2022, Kozicka et al. 2023, Sinke et al. 2023).

B) Reducing food loss and waste

The second element of our scenario is the reduction of food loss and waste along all parts of the food supply chain. At the retail and consumer stages, we assume a 50% reduction in food waste (Annex Chapter 4). As the share of fruits and vegetables in consumption increases, waste reduction for perishable products becomes particularly important.

Reducing food waste improves the resource efficiency and reduces the environmental footprint of the food system. According to Eurostat (2023b), almost 58 million tonnes of food were wasted in the EU in 2021. This translates to an annual food waste of 131 kg per capita. The associated market value of food loss and waste is estimated at 132 billion euro (European Commission 2023c).

Reducing food losses and waste requires improvements in producing, processing and consuming food. The waste hierarchy and the food waste hierarchy[28] provide guidance for the use of surplus food, byproducts and food waste. Measures to prevent surplus generation and food waste throughout the food supply chain are particularly important. Moreover, surplus food that is fit for human consumption is increasingly being redistributed through food banks and other networks. Food that is no longer fit for human consumption can be used as animal feed or for other bioeconomy purposes. The least favourable option is disposal without use.[29]

Key levers for reducing food waste (Section C in Chapter 4.3.4) are:

- **Monitoring** the amount of food waste along the supply chain to enable stakeholders to set targets, identify relevant prevention measures and develop valorisation opportunities (Flanagan et al. 2019).
- **Methods and technologies for forecasting** to allow a better adjustment of supply and demand (WRAP & WWF 2020).
- **Better cooperation** between actors in the food value chain to reduce inefficiencies along the chain (European Commission 2023c, UNEP 2024) and allow the establishment of redistribution networks.
- **Research** and advisory systems to support the extraction and recovery of (unavoidable) waste components for industrial applications, such as cosmetics, packaging products and pharmaceuticals, as well as the conversion of food waste into biomaterials, such as bioceramics and biopolymers (Sanchez Lopez et al. 2020).
- **Supporting consumers** to reduce food waste through prevention programmes that adopt systemic approaches and focus on interventions building on behavioural research and good practices from existing measures (Candeal et al. 2023). Moreover, fair food environments contribute to food waste reduction, for example through portion sizes in out-of-home catering, packaging sizes, and improved understanding of the "best before" and "use by" dates on food.

C) Creating fair food environments

The third element of our scenario are fair food environments. Food environments are "the physical, economic, political and socio-cultural context in which consumers engage with the food system to make their decisions about acquiring, preparing and consuming food" (HLPE 2017: 28). This context shapes and interacts with habits, routines and affective processes, and has a significant influence on food choices.

Emphasising the role of food environments acknowledges the limitations of the "responsible consumer choices" concept that has guided food policy for decades. This is based on the paradigm that awareness and knowledge about better food choices will motivate and enable people to make healthier food choices. While awareness, motivation, individual agency and literacy are important for shaping food behaviours, daily food choices are not only goal-directed and based on the best available information.

28 The waste hierarchy – developed in the 1970s to prioritise waste-management strategies – is part of the EU Waste Framework Directive (2008/98/EC), the EU Bioeconomy Strategy and EU Circular Economy Action Plan. The waste hierarchy has been adapted to food waste by JRC (2020).

29 Waste incinerated without energy recovery, waste sent to landfill or sewage disposal.

Rather, daily food choices and food behaviours are embedded and substantially shaped by the food environment in which individuals operate, with many structural factors beyond individual control (Herforth & Ahmed 2015, Swinburn et al. 2013). Therefore, results from interventions at the level of the individual, such as educational campaigns, typically yield only modest effects if there is no change in the food environment. The food environment is therefore the key factor in changing food consumption patterns at the individual and population level (European Commission & Group of Chief Scientific Advisors 2023, WBAE 2020). Food environments prevailing in the EU, however, are not conducive to healthy and sustainable food consumption patterns through a variety of factors, including price incentives, portion sizes and marketing for unhealthy foods. By exploiting people's biological, psychological, social and economic vulnerabilities they also drive obesity (Hall 2018, Osei-Assibey et al. 2012).

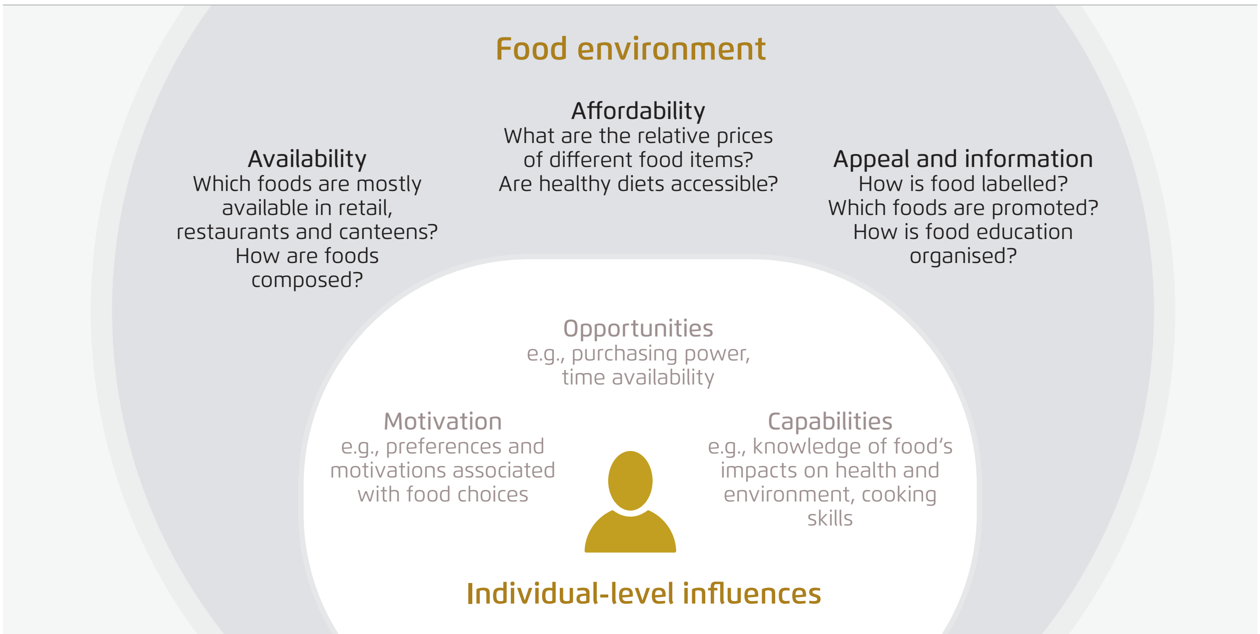
The creation of fair food environments supports consumers to shift to healthier, plant-rich diets and reduce food waste. In line with the German Scientific Advisory Board on Agricultural Policy and Food (WBAE 2020), we use the term "fair food environments", indicating that they:

- Are attuned to our human perception, decision-making capacities and behaviour,
- Are more health-promoting than current food environments,
- Have greater social, environmental and animal welfare compatibility, therefore supporting the well-being and livelihoods of current and future generations.

We conceptualise three main drivers through which food environments shape food consumption (Figure 13):

- **Availability:** The types of food available to people in their everyday lives are an important factor in determining what and how much is consumed. This includes supermarkets, shops, restaurants, online stores, ordering platforms, canteens, schools and neighbourhoods.
- **Affordability:** Adopting healthy and sustainable diets is influenced by income and prices. Price incentives that make healthy and sustainable

The importance of the food environment in influencing food consumption → Fig. 13



Agora Agriculture

diets more affordable can encourage changes in food consumption patterns.

- **Appeal and information:** Food consumption is shaped by information about food (e.g., labelling and education), as well as by the exposure to food and stimuli related to food (i.e., advertising). The influence of advertising and marketing on people's perceptions of foods and food brands often unconsciously affects what and how much is consumed.[30] The appeal of food is also influenced by social eating norms – the perceived standards for what constitutes appropriate consumption for members of a social group, such as the amount of food or specific food choices.

Food environments interact closely with three factors that shape individual behaviour:

- **Motivation:** which relates to both reflective processes, such as the intention to change food choices, and automatic processes, such as eating habits and preferred tastes.
- **Capability:** such as the ability to cook, the knowledge of food products and their sustainability impacts.
- **Opportunity:** the capacity to follow a certain food behaviour, such as having the time to prepare food, purchasing power and the influence of perceived social norms.

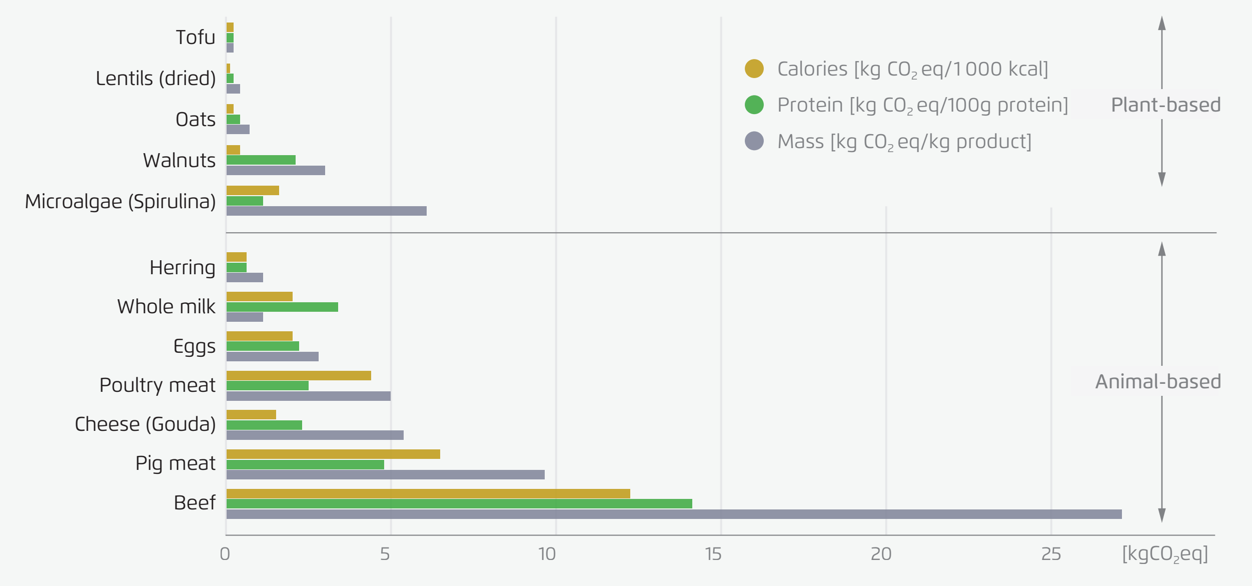
4.3.2 Environmental and climate impacts

The change in food consumption patterns associated with our scenario results in significant decreases in greenhouse gas emissions. This is mainly due to the lower emission intensity of plant-based food compared to animal products (Figure 14).

The greenhouse gas intensity of food consumption is determined mainly by the proportion of plant-based products. Most greenhouse gas emissions occur in the production part of the value chain.

30 Extensive and long-established evidence demonstrates that exposure of children to marketing for foods and drinks high in fats, sugars and salt significantly influences dietary behaviours and contributes to obesity (ECORYS et al. 2021, WHO 2022).

Greenhouse gas emissions* of protein-rich food products per protein content, kilocalories and weight → Fig. 14



Agora Agriculture based on Corsus GmbH (2024). * from production and processing

Changes in transportation distance, in contrast, have a comparatively small impact on the greenhouse gas relevance of a diet (Figure 15).

In our scenario, the reduction in the consumption of animal products largely translates into a decrease in livestock husbandry within the EU (Chapter 4.4.1). This results in a major contribution to lowering EU greenhouse gas emissions from agriculture and agricultural peatlands. Reducing livestock accounts for more than 150 million tonnes of CO_2 equivalent ($MtCO_2eq$) and thus approximately for 50% of total greenhouse gas emissions reductions in our scenario between 2020 and 2045 (Chapter 4.1).

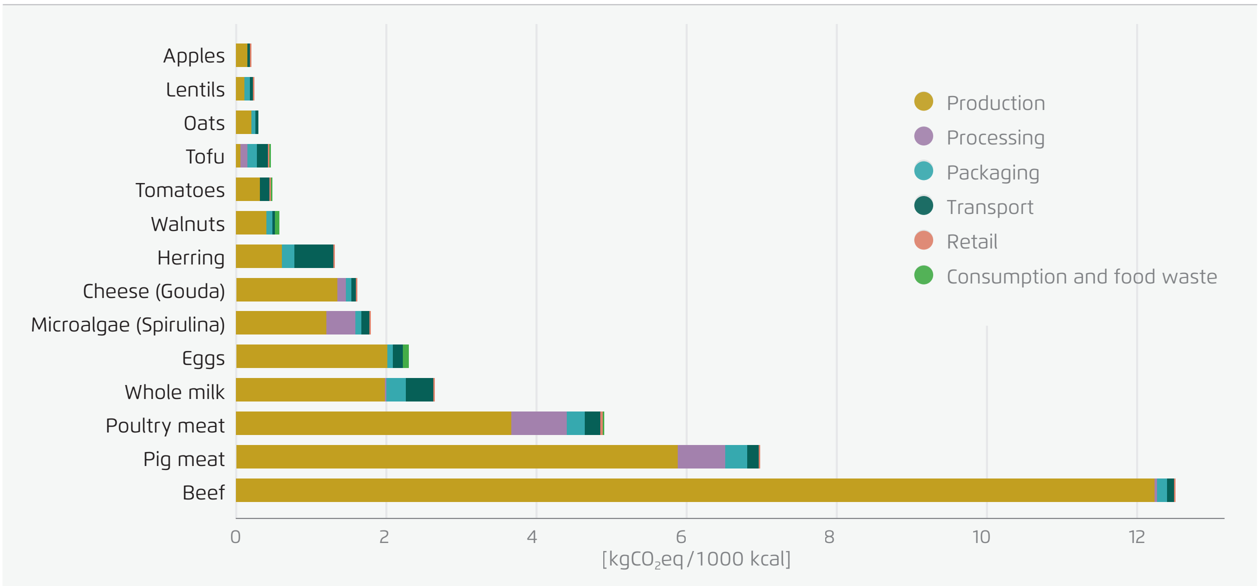
The shift in food consumption patterns and the resulting reduction in the demand for animal products leads to a strong reduction in animal feed demand (Chapter 4.1, Figure 5 and Annex Chapter 5):

- Arable land used for feed production in the EU is estimated to decline by 48% in 2045 compared to 2020. This alleviates pressure on land, creating opportunities for other uses, such as for biomass production for material use and for biodiversity conservation.
- The demand for imported feed also declines, resulting in a 60% reduction in the arable land needed in other parts of the world to produce that feed for the EU. This reduces pressure on global land resources and can indirectly contribute to global food security, biodiversity and climate change mitigation.

Finally, we conduct a sensitivity analysis in which we apply our scenario with all the anticipated changes in agriculture and forestry, while not changing 2020 food consumption patterns and not reducing food waste. Results illustrate that instead of the EU becoming a net exporter of virtual land of approximately 21 million hectares, the EU would become a net importer of about 15 million hectares of virtual land by mid-century in order to satisfy its food demand (Chapter 4.1, Figure 7 and Annex Chapter 2). The larger EU imports and the smaller EU exports of agricultural products would lead to increasing agricultural production in non-EU countries and additional greenhouse gas emissions in these countries of 59 $MtCO_2eq$ compared to our main scenario.[31]

31 Quantitative result on greenhouse gas emissions derived from a sensitivity analysis conducted in CAPRI.

Climate impact of food along the value chain → Fig. 15



Agora Agriculture based on Corsus GmbH (2024)

4.3.3 Health and socio-economic impacts

In our scenario, the average intake of food groups shifts towards an increased consumption of vegetables, fruits, legumes and nuts, while reducing sugar intake and aligning calorie levels with dietary reference values. Such a shift in consumption patterns can contribute to healthier diets and reductions in diet-related diseases. Although this study does not include a quantification of health impacts, extensive research demonstrates significant benefits associated with adopting healthier, plant-rich consumption patterns (Bui et al. 2024, Medawar et al. 2019, Wallace et al. 2020). An increased adoption of healthy diets will also decrease pressure on public health budgets (Laderchi et al. 2024).

In line with the "One Health" concept (Chapter 3.3), the reduction in the consumption of animal products has positive indirect health effects. For example, it alleviates pressure on land-based ecosystems due to a decreasing land demand for feed production, thereby helping to lower the global risk of emergence and spread of infectious zoonotic diseases. It also mitigates ammonia-related air pollution. The risk of antimicrobial resistance can also be reduced.

Internalising the external costs of some food products, for example by including agriculture-related greenhouse gas emissions into an Emissions Trading System (ETS) (Chapter 5.1) or through taxes on products with a high environmental footprint, would affect food prices and thus the cost of food. On the other hand, more sustainable consumption patterns that are plant-rich often result in lower costs compared to current diets (Springmann et al. 2021). In addition, policies can be designed to reduce food poverty and ensure that the transition to a more sustainable food system does not disproportionately impact socio-economically vulnerable households (Chapter 4.3.4)

4.3.4 Policy options

Food policy plays an important role in supporting a shift in food consumption patterns. Establishing fair food environments is essential, since many of the factors shaping food choices are beyond individual control. Current food environments in the EU are often a barrier to healthier and more sustainable diets.

Creating fair food environments requires a combination of diverse instruments and a broad policy mix across different policy areas. While voluntary instruments are an important element, fiscal measures and public regulation are indispensable (European Commission & Group of Chief Scientific Advisors 2020, 2023).

An approach to food policy that integrates several dimensions, such as health, environment and agriculture, is still in its early stages of development. The EU has no common food policy, and as a result, policies targeting different parts of the food system often lack coherence. This lack of coherence has been identified by the Science Advice for Policy by European Academies (SAPEA) as one of the key obstacles delaying the transition to more sustainable food systems (European Commission & Group of Chief Scientific Advisors 2020, 2023). An integrated approach to food policy that is based on common objectives and principles has the potential to address current inconsistencies. This section describes three main areas for EU policy action:

A) Develop a legislative framework to promote sustainable food systems
B) Create fair food environments
C) Reduce food loss and waste

A) Develop an EU legislative framework to promote sustainable food systems

A legislative framework to promote sustainable food systems would build the foundation for an integrated EU food policy, as it would define the overarching objectives, principles and processes to strengthen coherence in food system policies.

An integrated food policy takes a "food systems approach" by linking various policy areas (horizontal integration), coordinating different levels of government (vertical integration) and involving a diverse range of stakeholders, including the public and private sectors, as well as non-governmental organisations (Parsons 2019). This makes it possible to leverage synergies and co-benefits between policy areas, manage trade-offs and create more coherence between policy levels. Given the distribution of competences across policy levels, improving multi-level governance is a particularly important focus area (Figure 16).

To advance a more sustainable EU food system, it will be critical to build on the initiative for an EU Legislative Framework for Sustainable Food Systems (FSFS).[32] We consider two aspects to be critical for the functioning of such a legislative framework (Figure 17), namely its potential to:

- Set the parameters for a future evolution of the EU food system, by outlining definitions, overarching principles (such as the precautionary principle and the One Health approach), key objectives (including for the environment and health) and processes to strengthen coherence in food system policies.
- Require member states to develop national food strategies and action plans.

32 A proposal for an EU Legislative framework for sustainable food systems was first announced in the Annex of the Farm to Fork Strategy and was foreseen to be published in 2023. It was first delayed and then absent in the publication of the European Commission's 2024 work programme.

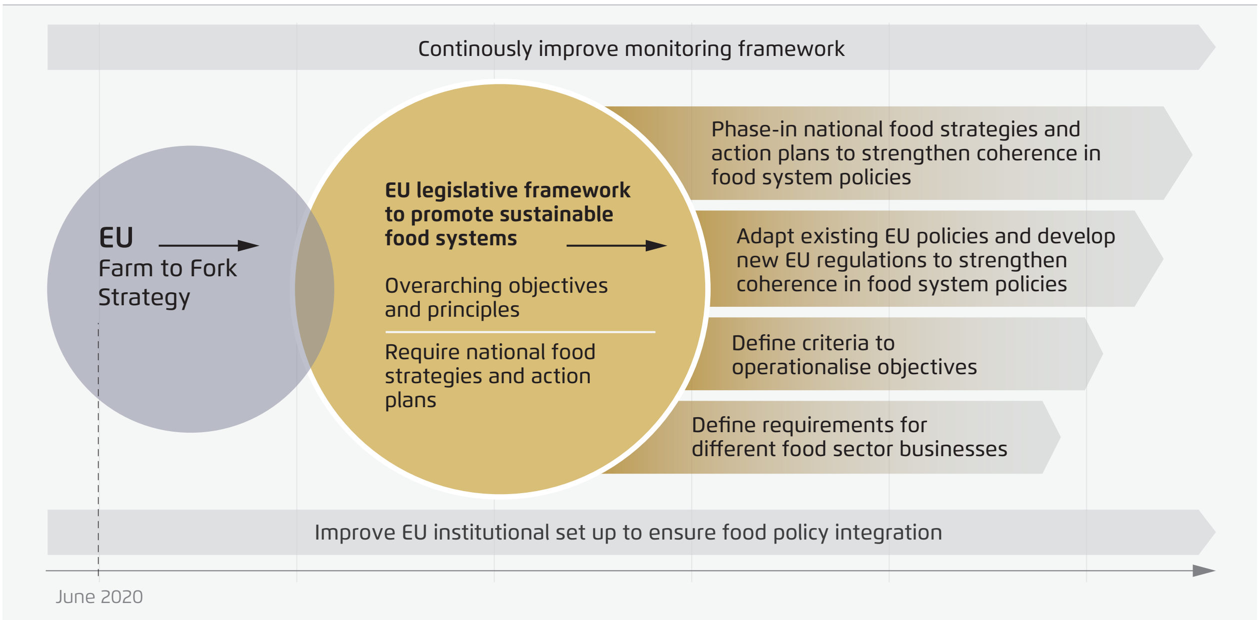
This legislative framework would serve as a foundation for the progressive advancement of integrated food policy over time. Its most important elements are:

- **National food strategies and action plans.** Member states would have to develop national food strategies and action plans to implement the objectives of the legislative framework. In regular reports to the European Commission, member states would describe their measures to achieve the objectives and how they implement food environment policies, providing information in line with an EU monitoring framework. Very few countries in Europe have so far set up integrated food strategies.
- **Coherence of EU policies with the established objectives.** To strengthen policy coherence, new and existing policies will have to respond to the objectives and principles set in the legislative framework. This relates to all policies with an impact on food systems, ranging from agriculture and fisheries, to trade, climate and social policies.

An integrated food policy for the EU, exploring the role of a legislative framework → Fig. 16

Agora Agriculture

Architecture and key elements of an EU legislative framework to promote sustainable food systems → Fig. 17

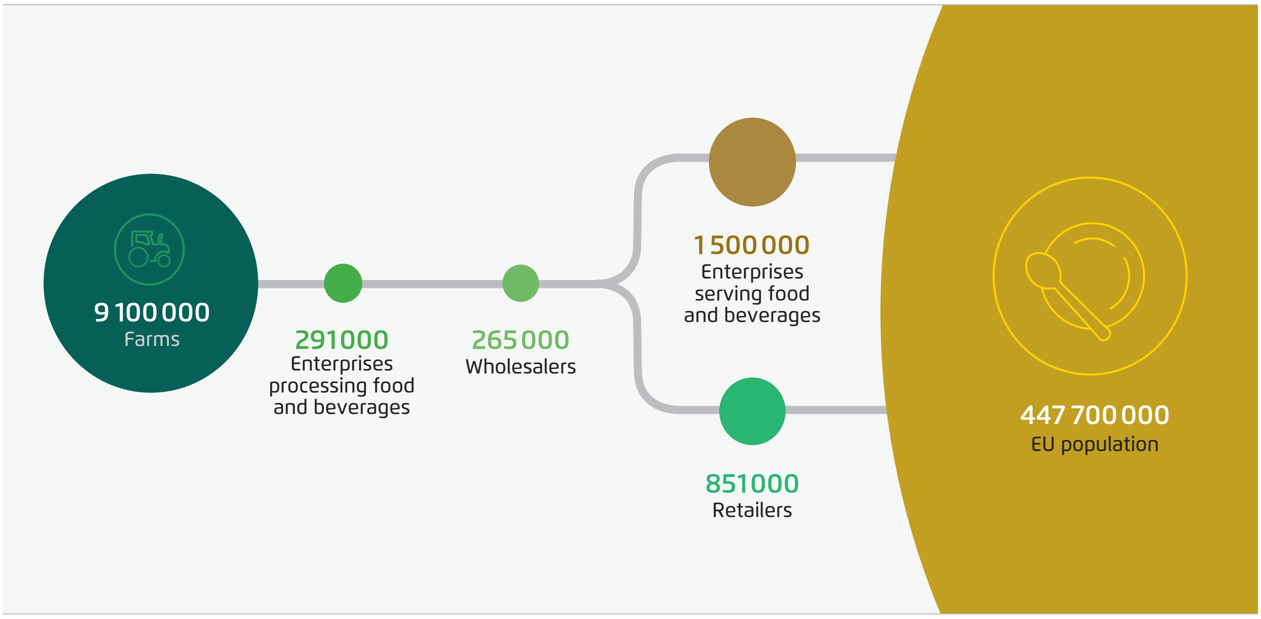


Agora Agriculture

- **Criteria to operationalise objectives.** The successful implementation of the legislative framework would be supported by the definition of criteria and indicators for the established objectives. Such criteria would form the basis for a monitoring framework for food systems at the EU and member state level. While some food-related criteria already exist at the EU level and in individual member states, improved monitoring is still needed in many areas, such as food poverty and food environments (Fanzo et al. 2021).
- **Requirements for food sector businesses.** The legislative framework would provide orientation not only for public authorities, but also for food sector businesses. Actors in the "middle of the chain" such as food processors, wholesalers and retailers, situated between producers and consumers, hold great market influence (Figure 18). They have an important role in changing food systems and possess the leverage to drive sustainability improvements along the value chain (EEA 2023e, Walton 2023). After the legislative framework has set objectives and principles, it will be necessary to explore the need for more specific requirements for businesses in the food sector. This process will need to consider and build on experiences with recent EU policy initiatives related to corporate due diligence.[33]
- **Improved EU institutional set-up to ensure food policy integration.** Changes within EU institutions and decision-making processes are needed to develop and implement food policies with a food systems approach. Member states could be supported in setting up national food strategies and effective measures through an EU platform aimed at facilitating exchanges between member states, regional authorities and selected further actors in the food system, such as research institutions. The structure and set-up of this platform could build on the experiences of the EU Platform on Food Losses and Food Waste (Bock et al. 2022).

33 Including the Corporate Sustainability Due Diligence Directive ((EU) 2024/1760), the Corporate Sustainability Reporting Directive ((EU) 2022/2464) and the Deforestation-free Products Regulation ((EU) 2023/1115).

Number of food chain actors in the EU in 2020 and importance of middle of the chain actors* → Fig. 18



Agora Agriculture based on Eurostat (2023e). *exemplary depiction of the value chain

B) Create fair food environments

Food environments play a key role in shaping consumer choices (Chapter 4.3.1). To acknowledge the role of food environments as part of an integrated food policy requires a paradigm shift in policy making, with a focus on interventions that go beyond merely providing information to consumers. A learning policy design is essential, as an integrated approach to food policy is relatively new and requires further experience with effective policy mixes (European Commission & Group of Chief Scientific Advisors 2020, OECD 2021). While many policy areas need to be addressed, five measures stand out for their significant potential to promote fair food environments:

1. Health and sustainability criteria in public food procurement (improving availability)
2. Labelling framework (improving information)
3. A conducive marketing environment (improving appeal)
4. Protein diversification (improving availability)
5. Price and social policies (improving affordability)

1. Health and sustainability criteria in public food procurement

Purchasing decisions made in public canteens, including those in kindergartens, schools, hospitals and retirement homes, can have transformative potential. When public food procurement practices align with food policy objectives, they can catalyse broader societal shifts towards healthy and sustainable diets. In addition to the purchasing power of the public sector, public procurement decisions also help shape norms around food consumption and production (Swensson et al. 2021). Fully leveraging this potential will require establishing EU-wide mandatory minimum health and sustainability criteria for public procurement. These can build on the voluntary green public procurement guidelines of the European Commission (European Commission 2019a), particularly in terms of promoting plant-rich menus.

However, even with changed sustainability requirements, legal uncertainties remain with regard to the question of whether and how buying authorities could support regional supply chains[34] through procurement (SMEKUL 2021, WBAE 2020). Currently, the EU public procurement directives restrict the ability to prefer regional food sources.[35] The possibility of adapting procurement rules should therefore be explored to make exceptions for regional food producers (IASS 2022).

2. Labelling framework

Food labels can help consumers make informed choices by giving insights about the health characteristics of food products and the environmental impacts related to their production. They also provide signals along the value chain, such that producers aiming for better labels and rankings need to change their production practices, for example through reformulation and sourcing. The introduction of a mandatory and harmonised EU front-of-pack nutrition labelling scheme would improve the current situation. This could be extended to a sustainability label, including information about aspects such as climate impact, health and animal welfare. Moreover, improving the date-marking of food products (e.g., "use by" and "best before" dates) would contribute to the reduction of food waste.[36] Labels have varying impact on different socio-economic groups and appear most effective among people with a higher education (European Commission & Group of Chief Scientific Advisors 2023). Labels therefore need to be complemented with other instruments to improve healthy and sustainable food consumption.

34 While building regional supply chains may not strongly reduce greenhouse gas emissions through shorter transportation, they can contribute to achieving other sustainability objectives, e.g., by closing nutrient cycles and supporting rural development and reducing food waste of perishable foods.

35 Referring to the requirement: "Unless justified by the subject-matter of the contract, technical and functional requirements shall not refer to a specific make or source (...)", as established both within the Directive on public procurement (2014/24/EU) and the Directive on the award of concession contracts (2014/23/EU).

36 The proposal for a revision of the Regulation on Food Information to Consumers ((EU) 1169/2011) on front-of-pack nutrition labels, improved date marking of food products etc., is currently delayed.

3. A conducive marketing environment

Three marketing-related themes require specific EU policy attention:

- A comprehensive regulatory approach is needed to reduce the exposure of children and adolescents to the marketing of foods and drinks high in fats, sugars and salt. Despite long-standing recommendations to limit children's exposure, a review of policies across European countries showed a fragmented and inadequate approach to addressing marketing (WHO European Region 2018). Such policies can be effective, especially when they are mandatory and include children above the age of 12 (Boyland et al. 2022, Calvert 2021). Adequate regulation will require coordinated action at the EU, national and local levels. To create a level playing field across the EU, marketing that can influence children across multiple member states – whether through digital media, television, sponsorship of large sports events or product packaging – should be effectively regulated at the EU level.
- The EU co-funding rules for information and promotion campaigns for European food products (Regulation (EU) 1144/2014) could be revised. The policy has a budget of about 180 million euro per year for marketing campaigns (European Commission 2023g). While some money has been reserved for the promotion of fruits, vegetables and foods with sustainability labels, the rationale of the entire policy may be shifted towards promoting only those foods whose consumption would increase as part of healthy and sustainable diets.
- Plant-based alternatives to animal products are often named with a reference to their animal counterparts. Whether or not they can be marketed as "vegetarian schnitzel" or "vegetarian sausage" plays a role, since the name indicates the expected taste and the type of use, which helps consumers identifying the suitable alternative product (Jetzke et al. 2022). At the same time, most consumers are not confused by vegetarian meat-alternatives that carry the name of the product category of their animal product counterparts, as long as they are

clearly labelled as vegetarian or vegan. This was shown in a survey in 11 European countries in 2020 (BEUC 2020). Reducing existing barriers to labelling plant-based dairy-product alternatives[37] and not creating additional barriers to the marketing of vegetarian or vegan alternatives for other livestock products would support the shift towards more plant-rich diets.

4. Protein diversification

The increased availability and affordability of plant-based and other alternative proteins, such as fermentation-derived microbial proteins, can expand food choices and facilitate more sustainable consumption patterns. Introducing an EU Protein Diversification Strategy could be an important catalyst for creating the conditions for the market expansion of foods containing plant-based and alternative proteins. This strategy would help align supply and demand for such proteins, increasing growth and innovation in the sector.

In 2023, the European Parliament adopted a resolution on a European Protein Strategy (European Parliament 2023a) in response to the European Commission's announcement that it would revise its 2018 report on plant protein development. This process provides a window of opportunity for the introduction of an EU protein diversification strategy during the 2024–2029 EU legislative cycle.

Key elements and areas of action of such a strategy could include:

- Upscaling and promoting plant-based protein sources for human consumption.
- Incentivising the valorisation of agricultural by-products and food waste for plant-, cell- and fungi-based alternatives.
- Securing a supporting regulatory framework for alternative proteins. This includes increasing the capacity of the European Food Safety Authority to ensure the approval procedure for novel foods within 18 months, which is the foreseen timeframe.
- Investing in strategies that match supply and demand of plant proteins for human consumption, for example through the support of regional supply-chain managers.
- Monitoring developments in plant- and animal-based proteins in food and feed production and consumption in the EU.

5. Price and social policies

The costs of food production and consumption patterns in the EU are currently largely externalised, for example by burdening the healthcare system and the environment. Policy measures should aim at internalising these external costs, which would help to make healthy and sustainable diets relatively more affordable. Financial instruments such as taxes and subsidies have been shown to have an impact on both the food industry and consumption patterns; they can therefore play a role in designing fair food environments at the national level. At the EU level, the introduction of an ETS for agriculture-related emissions would affect prices for food products with high greenhouse gas emissions (Pérez et al. 2016, Stepanyan et al. 2023).

At the same time, social policies and financial instruments are needed to alleviate food poverty in the EU, and constitute a precondition to providing healthy and sustainable diets for all (European Commission & Group of Chief Scientific Advisors 2023). If the costs for food and healthy, sustainable diets increase, policies would need to be designed ensuring that the financial impact does not disproportionately affect socio-economically vulnerable households (EEA 2024b). While most policies need to be designed at national level, the European Commission could support member states by conducting an independent evaluation of instruments to tackle food poverty. Based on the outcomes of such an evaluation, the Commission could propose a Fair Food Initiative,

37 Using dairy names for plant-based products such as "milk", "cheese", "yoghurt" and "butter" has been prohibited in the EU (Regulation (EU) 1308/2013), and this ban was confirmed by the European Court of Justice in 2017 (Case C-422/16). Only a few exceptions apply for traditional uses, such as peanut butter and coconut milk (Commission Decision 2010/791/EU).

potentially integrated into the European Pillar of Social Rights. This initiative could include an action plan and specific targets to support member states in increasing access to healthy and sustainable diets across the EU.

Policies in these five areas offer multiple benefits. They facilitate the adoption of healthy and sustainable diets, tackle obesity and food poverty and improve the sustainability of food systems. These areas are crucial for promoting healthy, plant-rich diets and food waste reduction.

C) Reduce food loss and waste

Despite political commitments made at the EU and member state levels, action taken so far in member states has not led to a sufficient reduction of food waste levels to meet the Sustainable Development Goals (SDGs) target 12.3 dealing with food loss and waste (see below). This mainly due to the lack of a systemic, evidence-based and coordinated approach in member states (European Commission 2023h, 2023c). Four areas for future EU policy actions are important to reduce food loss and waste:

- **Legally binding food waste reduction targets in line with SDG 12.3.** The SDG 12.3 aims to halve per capita food waste at the retail and consumer levels and reduce food losses along the production and supply chains.
- **Inclusion of food loss and waste in primary production in reduction targets and measurement**. Pre-harvest losses should be monitored and strategies should be developed to reduce them. With improved data and a clearer understanding of the underlying causes, targets for reducing food losses during primary production should be established, along with support for effective implementation (Infobox 3).
- **Improve the robustness of data**. The reporting requirements for member states need to be revised to improve the robustness of food waste data (Infobox 4 for limitations of the current approach to data collection and monitoring requirements, and Figure 19 on the occurrence of food loss and waste along the value chain). For example, member states would substantiate their reporting of primary data on waste generated along the food supply chain, thereby contributing to a more accurate and reliable picture on food waste generation. Primary data is also needed to design and evaluate

Infobox 3: Pre-harvest food losses as a missing part of EU food waste monitoring

The definition of food waste in the EU Waste Framework Directive (2008/98/EC)[38] is based on the definition of food in the General Food Law (Regulation (EU) 178/2002). Food waste is any food that has entered the food supply chain (post-harvest) and is then removed or discarded from the chain or at the final consumption stage and processed as waste. By-products from the production of food, used as feed or other uses, are not defined as food waste. However, the categorisation of food waste versus by-products is interpreted quite differently by the member states (European Commission 2023f). A robust definition and further harmonisation of data is needed (European Commission 2023f).

Due to the food definition, pre-harvest losses are currently not addressed by the Waste Framework Directive, although the international "Food loss and waste reporting and accounting standard" providing guidelines for SDG 12.3, recommends addressing the food supply chain from the point at which the raw materials for food are ready for harvest or slaughter. Recent studies show that food losses in primary production (including pre-harvest and post-harvest losses) are significant (Bajzelj et al. 2019, De Laurentiis et al. 2023, WWF UK 2021). A summary report of seven studies dealing with losses at the farm level in Sweden shows that up to 30% of production becomes food losses (Lindow et al. 2021).

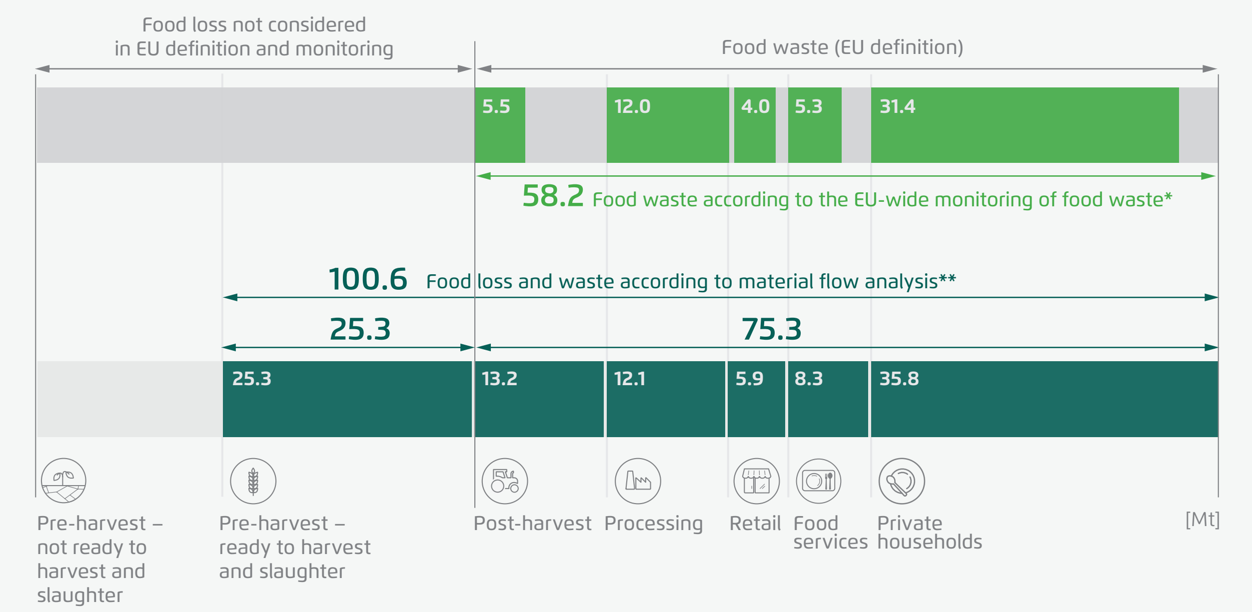
[38] The definition of food waste was established in a 2018 amendment: Directive (EU) 2018/851.

Infobox 4: Improving the data and monitoring requirements for food loss and waste within the EU

Member states are obliged to measure and report the amount of food waste at all stages of the food supply chain using the common methodology set out in Annex III of Commission Delegated Decision (EU) 2019/1597. In 2021 the total amount of food loss and waste was around 58 million tonnes, or 131 kg per capita. This ranged from 68 kg per capita for Slovenia to 397 kg per capita for Cyprus (Eurostat 2023b). Reports of the member states have not yet been published; nor is there a scientific review of the quality and validity of the reports available. Studies using mass-flow analysis as a methodological approach generally result in higher food loss and waste estimates along the value chain (Caldeira et al. 2019, 2021; De Laurentiis et al. 2023). These differences are more significant for early stages of the chain. One cause could be an underreporting in the statistics, as waste generated at these stages can be treated on site (such as by composting, incinerating residues to produce energy or anaerobic digestion) and might not be reported in the waste statistics.

Monitoring results for food waste and loss at each step of the value chain needs to be carefully reviewed to capture and assess the upstream and downstream effects and the underlying causes: waste shares at the retail level are usually much lower than shares reported for other parts of the value chain (Eurostat 2023b). However, scientific studies show that loss and waste in primary production and processing are partly a result of retailers' buying and trading practices, such as their high-quality requirements and cosmetic standards for fruits and vegetables that lead to food losses at farm level (Herzberg et al. 2022, Lindow et al. 2021, Verbraucherzentrale Niedersachsen e. V. 2022, WWF UK 2021). At the same time, expectations and buying practices of consumers, for example regarding product range and cosmetic standards, influence sales practices at the retail level.

Food loss and waste occurring along the value chain in the EU – overview of the scope of the problem and ambiguity of data → Fig. 19



Agora Agriculture based on * Eurostat (2023b) ** De Laurentiis et al. (2023)

efficient food waste prevention strategies and measures (Caldeira et al. 2019). The anticipated revision of the Waste Framework Directive in 2027 gives the European Commission an opportunity to consider a mandatory reporting system for businesses to enhance transparency on food loss and waste and to improve data being reported to the Commission.[39]

- **Allow safe use of catering waste as feed for animals.** Regulation (EC) 1069/2009 and implementing Regulation (EC) 142/2011 laying down health rules as regards animal by-products currently ban using kitchen leftovers and catering waste for feed. Given the availability of practices for achieving adequate pathogen inactivation, regulations could be revised to permit safe methods for utilising catering waste as feed for non-ruminants.[40] Enhancing the use of food waste as feed improves resource efficiency and reduces reliance on domestic crop production and imported feed and related environmental impacts (Boumans et al. 2022, Nakaishi & Takayabu 2022, Nath et al. 2023).

4.4 Livestock farming

4.4.1 Scenario

Changes in livestock production are essential for the agricultural sector to effectively contribute to societal sustainability goals. These changes contribute to the reduction of greenhouse gas emissions, biodiversity protection in the agricultural landscape and decreased pressure on global land resources. In addition to shifts in consumption leading to reduced production of animal products (Chapter 4.3), the livestock sector can become more sustainable by adopting greenhouse gas mitigation technologies, increasing the share of feed sourced from grasslands and agricultural residues, and implementing management and husbandry practices that provide higher animal welfare.

As livestock and feed production account for over 50% of the value of total agricultural production in the EU (Eurostat 2023e 2023g), implementing significant changes presents challenges for the entire sector. A political framework with a reliable development path can support the sector to manage these changes. This process would require stepwise adaptations of regulation and long-term commitments for financial incentives, as well as consumer policies.

The scenario includes the following elements for livestock farming:

A) Reduced animal production
B) Upscaling greenhouse gas mitigation technologies
C) Adapting feeding
D) Enhancing animal welfare.

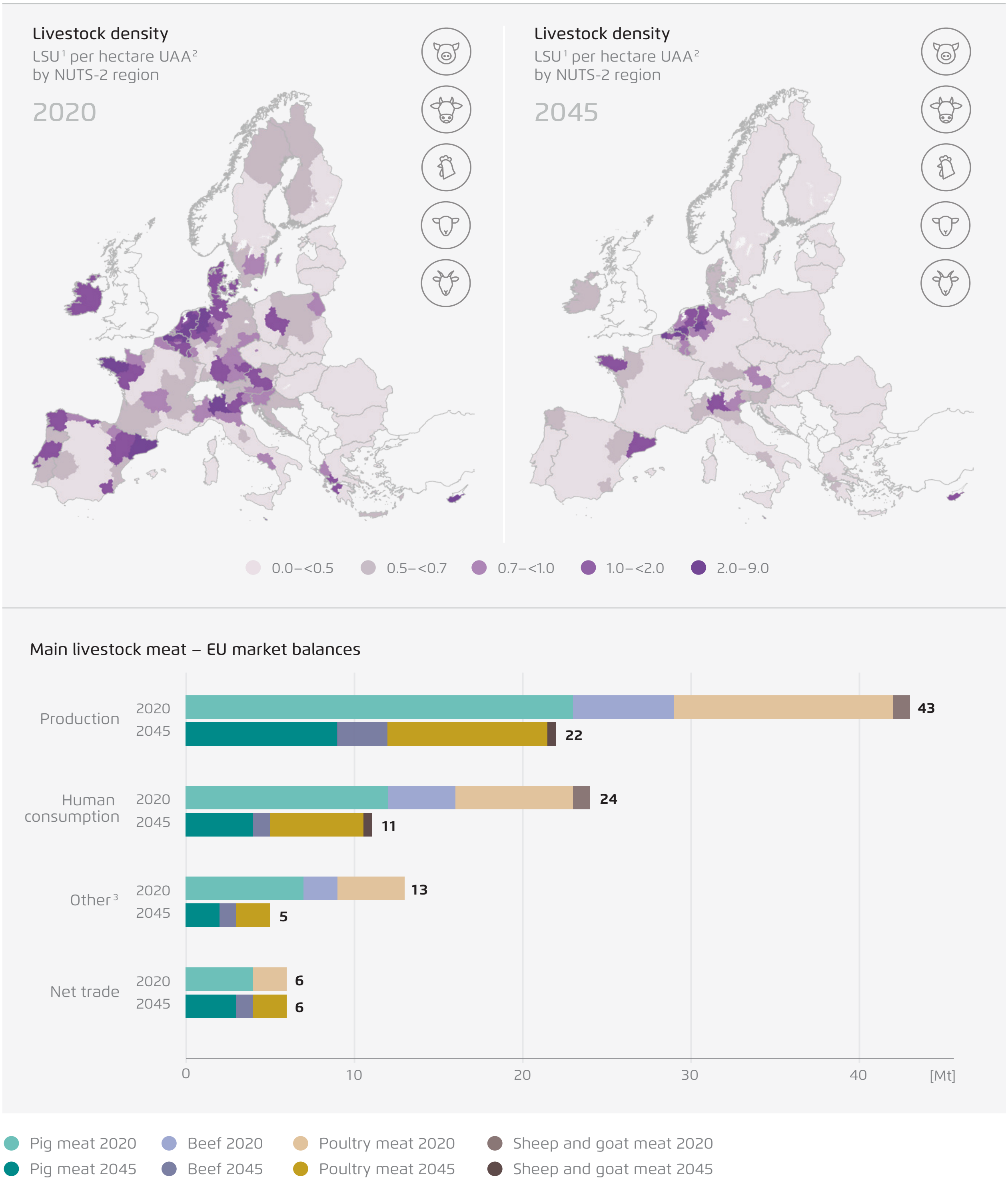
After outlining the elements of the scenario, we examine the ecological effects on climate, land use and biodiversity. Furthermore, we analyse the projected economic effects, such as market balances of feed and animal products. In Chapter 4.4.4 we discuss EU policy options to incentivise and support the changes outlined in the scenario.

A) Reduced animal production

Reducing both the consumption and production of animal products contributes to mitigating climate change and environmental degradation. Reducing consumption helps prevent the possibility of increased animal product imports into the EU, which could offset these benefits. In our scenario, decreasing the consumption of animal products within the EU is the main driver of reduced livestock production (Figure 20). The extent of reduction in consumption per species is determined by different factors, including their ecological impact, land use efficiency and current consumption trends (Chapter 4.3).

39 This can draw on the experiences made in Austria that introduced such an obligation in 2023 (BGBl. I Nr. 66/2023, Bundesgesetzblatt für die Republik Österreich).
40 Different processes are available, e.g., heat treatment, acidification and biosecurity processes and are currently used e.g., in Japan, Taiwan and South Korea (Shurson et al. 2023). Central to the safety of using surplus food is that food waste is treated in specialist licensed treatment plants which comply with stringent biosecurity measures (Luyckx et al. 2019, REFRESH 2019).

EU livestock densities and meat market balances in 2020 and 2045 → Fig. 20

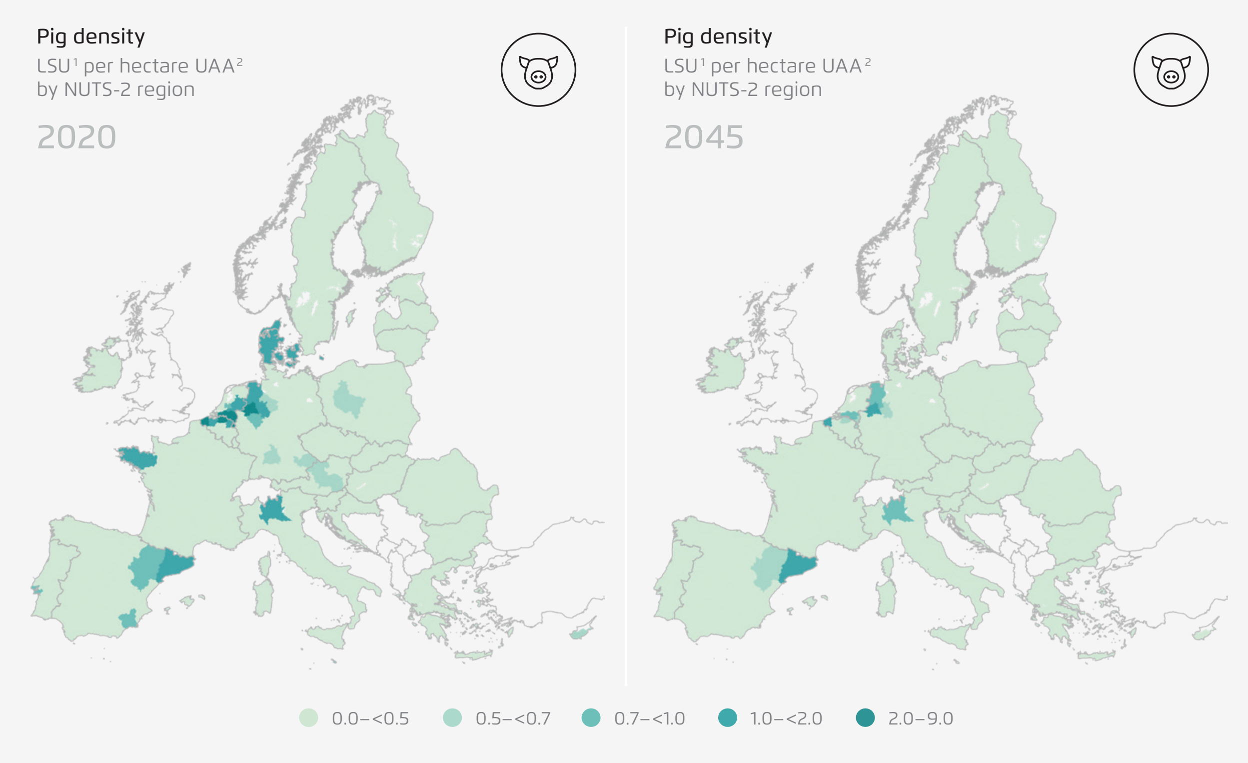


Agora Agriculture based on CAPRI results. [1] LSU = Livestock Unit; [2] UAA = Utilised Agricultural Area; [3] Other = waste, industrial and other uses

In this context, beef and milk consumption have a complex impact. On the one hand, ruminants produce significantly higher greenhouse gas emissions per unit of product compared to pigs and poultry, with methane from cattle, sheep and goats accounting for over half of the EU's agricultural sector emissions in 2020

EU pig densities in 2020 and 2045

→ Fig. 21



Agora Agriculture based on CAPRI results. [1]LSU = Livestock Unit; [2]UAA = Utilised Agricultural Area

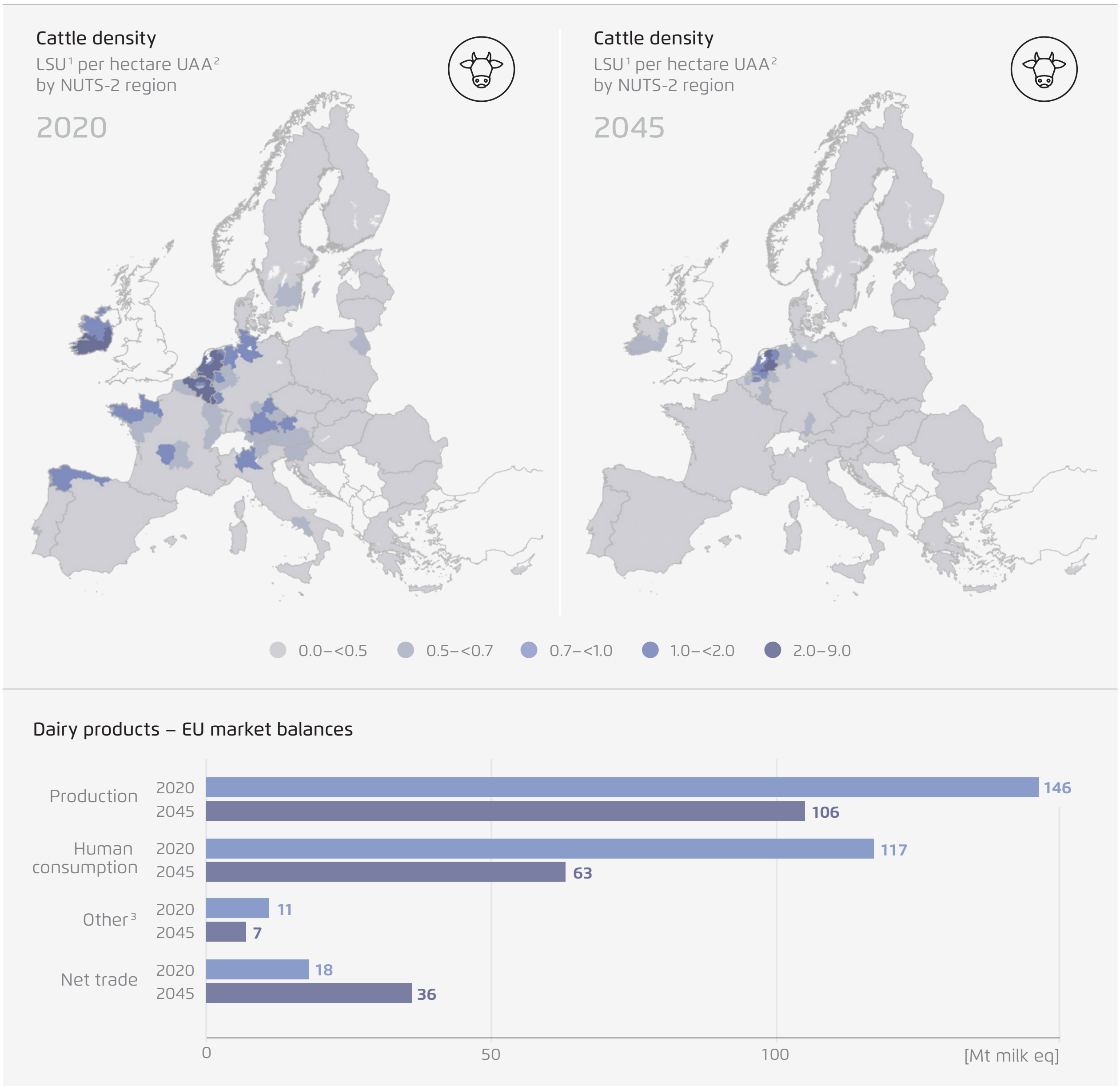
(European Union 2023b). On the other hand, when managed sustainably, ruminant farming can offer positive economic and environmental benefits. Ruminants can convert non-edible biomass into edible protein for humans, providing a cost-efficient approach for utilising grassland resources (Flachowsky et al. 2017, van den Pol-van Dasselaar et al. 2021). Additionally, they can support other ecosystem services in grasslands, such as biodiversity, nutrient cycling and carbon sequestration (Milazzo et al. 2023, Wróbel et al. 2023). Pigs and poultry have significantly lower greenhouse gas emissions per product unit than cattle and other ruminants. However, their reliance on arable crops for feed leads to competition for land that could otherwise be used for food production. As a result of these considerations, the average per capita consumption of beef and pork is reduced by 60–67% and of poultry, which is substantially more feed efficient, by 18% by 2045 compared to 2020 (Chapter 4.3.1).

The degree to which reducing consumption leads to lower production depends on the competitiveness of EU production in international markets. The EU has a comparative advantage in dairy production due to its abundant grasslands and favourable climatic conditions. Therefore, in our scenario the decrease in EU dairy production is less than the reduction in EU consumption, leading to an increase in exports. In contrast, the decline in production for pig meat and poultry meat closely aligns with the decrease in consumption. This is because pig and poultry production are highly standardised internationally, reducing the likelihood that the EU will maintain a long-term comparative advantage. Additionally, animal welfare standards increase in the EU under our scenario, which increases domestic production costs. Even if farmers receive public animal welfare payments to offset these costs, as suggested in this study, it is unlikely that taxpayers would agree to such payments covering large quantities of meat exports.

Reduction rates by 2045 compared to 2020 differ among livestock species:

- Pig production undergoes the biggest decline. There is a 64% decrease in fattening pigs and a 70%

EU cattle densities and market balances for dairy products in 2020 and 2045 → Fig. 22



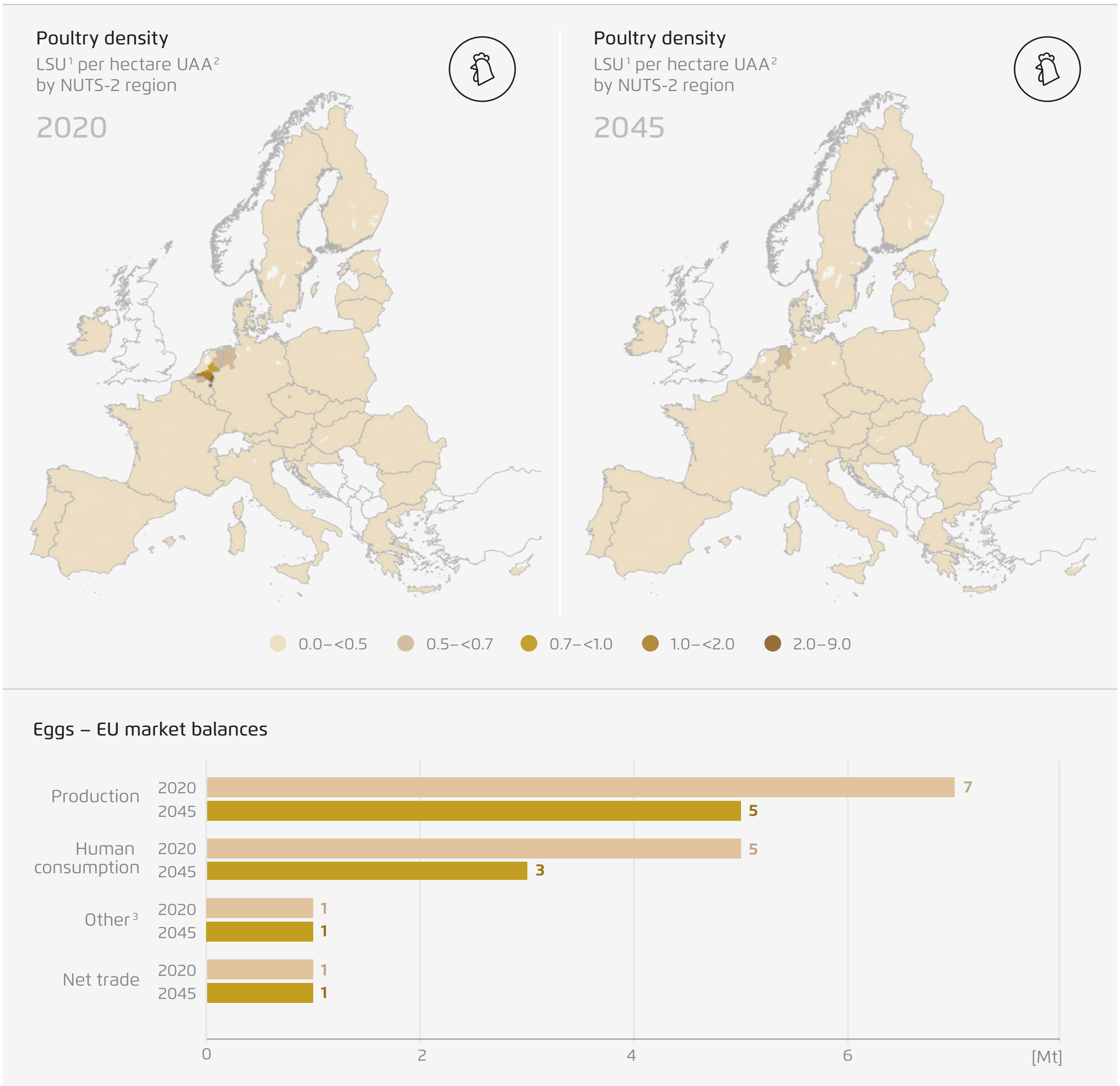
Agora Agriculture based on CAPRI results. [1] LSU = Livestock Unit; [2] UAA = Utilised Agricultural Area; [3] Other = waste, industrial and other uses

decrease in breeding sows across the EU (Figure 21). Exports remain virtually stable due to the drop in demand in the EU.

– The cattle population in the EU decreases by about 52% in our scenario (Figure 22). This decline differs between beef cattle,[41] with a 71% reduction, and dairy cows, with a 45% reduction. The significant decline in the production of beef cattle can be attributed to the fact that most of the beef is produced as a by-product of milk production. Calves born and not raised to replace old dairy cows are raised for beef. Due to the relatively smaller decline in milk consumption compared to beef, the share of beef cattle declines and leads to a significant reduction in suckler-cow husbandry. This is consistent with the fact that beef from suckler-cow herds usually results in higher greenhouse gas emissions than beef produced as a by-product of dairy production (Chapter 4.3.1).

41 Beef cattle are raised primarily for meat and not for dairy production (including both beef and dairy breeds).

EU poultry densities and market balances for eggs in 2020 and 2045 → Fig. 23



Agora Agriculture based on CAPRI results. [1] LSU = Livestock Unit; [2] UAA = Utilised Agricultural Area; [3] Other = waste, industrial and other uses

— Poultry fattening declines by 28%, a relatively smaller reduction compared to other livestock (Figure 23). This is due to poultry's higher feed efficiency and aligns with current consumption trends. Decreased consumption directly correlates with reduced production for both poultry and pigs.

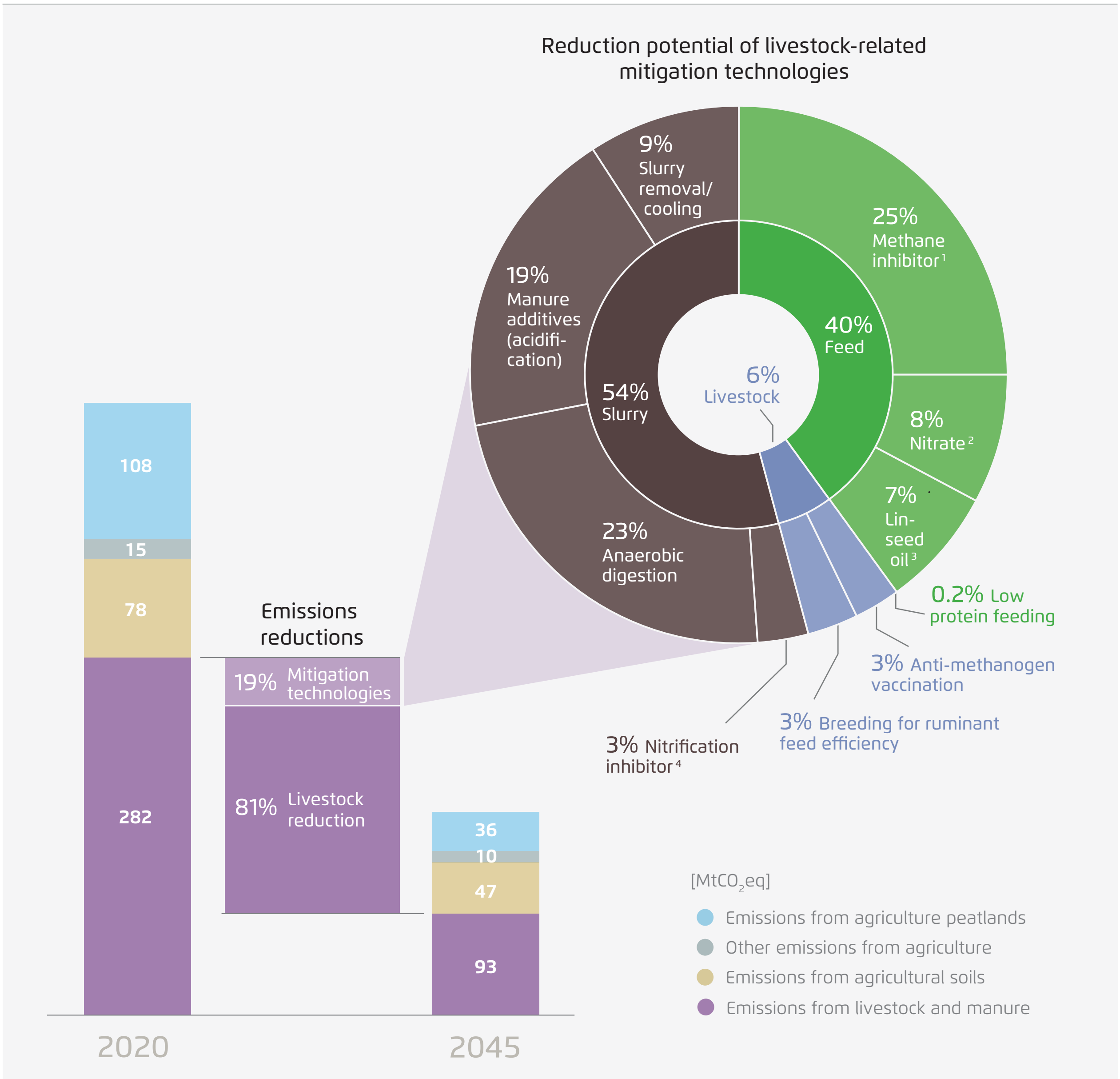
The reduced livestock population results in decreased manure production. Nitrogen supply from manure of cattle declines by 54%, from pig fattening by 60% and from poultry fattening by 29%. Although the nitrogen content in manure varies depending on the digestibility of feed components, the overall decrease in animal numbers and manure leads to a substantial reduction in greenhouse gas emissions and alleviates environmental pressures. This reduction occurs despite higher per-unit emissions due to lower feed efficiencies, as ruminant diets have higher inclusions of forage from grassland and pig and poultry diets use more food waste and food-by-products. Regions with previously high animal densities benefit significantly from improved manure management, which reduces pathogen spread and mitigates water and air pollution.

B) Upscaling greenhouse gas mitigation technologies

Greenhouse gas emissions from the livestock sector can be reduced by various mitigation technologies. Reduction technologies primarily target methane

Share of greenhouse gas emissions from livestock in 2020 and 2045 and the contribution of mitigation technologies

→ Fig. 24



Agora Agriculture based on CAPRI results, Ambrose et al. (2023); Cahalan et al. (2015); Dalby et al. (2023); Herrero et al. (2015); Hilhorst et al., (2002); Holtkamp et al. (2023); Ibidhi & Calsamiglia (2020); Kebreab et al. (2023); Luo et al. (2015); Minet et al. (2016); Ngwabie et al. (2016); Pérez Domínguez et al. (2020); Simon et al. (2020); Suleiman et al. (2016). Note: The percentages for all mitigation technologies do not sum to 100% due to rounding. [1] 3-nitrooxypropanol, feed additive; [2,3] feed additive; [4] dicyandiamide, slurry additive

(CH_4) and nitrous oxide (N_2O). The most effective technologies are manure-management practices and improved livestock feeding. We estimate the greenhouse gas reduction potential of ten mitigation technologies that are adapted to different animal types and husbandry systems (Figure 24 and Annex Chapter 5).[42]

According to our calculations, the implementation of mitigation technologies could lead to a reduction of about 37 million tonnes of CO_2 equivalent ($MtCO_2$ eq) per year in our scenario, accounting for 19% of the total reductions in the livestock sector. Considering the uncertainties associated with the effectiveness of each technology and their combined impacts, we estimate that the potential emissions savings could range from 26 up to 47 $MtCO_2$eq.[43]

The largest contribution to the total reduction potential of these mitigation technologies is achieved through methane inhibitors (25%), anaerobic digestion (23%) and manure additives (19%):

- **Methane inhibitors** (e.g., 3-Nitrooxypropanol) are feed additives that disrupt the activity of specific enzymes crucial in methane production by methanogenic archaea.
- **Anaerobic digestion** reduces methane emissions by using microorganisms to decompose animal waste in an oxygen-deprived environment, typically in biodigesters. This process yields biogas, which is captured and used as a renewable energy source.
- **Manure additives** (e.g., acidification with sulphuric acid) lowers the pH value of the manure, which in turn suppresses microbial activity and reduces the release of emissions (methane and ammonia). Manure is acidified during storage or before field application.

The effectiveness of technologies in reducing emissions may be limited by the housing system, as their implementation can conflict with outdoor- or pasture-based husbandry practices. Administering feed additives to animals in pasture-based systems is more challenging than in indoor feeding systems. Additionally, the potential for effective manure management is reduced as outdoor animal waste increases due to an increasing share of animals kept on open land or pasture.

The technology of feed additives shows the greatest impact in systems with intensive production levels. However, in certain cases, it might be more beneficial to change the husbandry system itself rather than applying mitigation technologies (Reinsch et al. 2021).

C) Adapting feeding

By 2045, changes in feed composition for ruminants and non-ruminants are expected to reduce competition between food and feed resources and enhance animal welfare for ruminants compared to 2020. The share of grassland-based forage (i.e., fresh cut, hay and silage[44]) for ruminants increases, while non-ruminants consume a higher share of food waste and agricultural by-products (Boumans et al. 2022, Ertl et al. 2015, Sandström et al. 2022). Based on changes in livestock numbers, feed composition and dietary shifts, we calculate a 46% decrease in total animal feed consumption in the EU under our scenario, with a 50% reduction in consumption of feed cereals and feed concentrates. Considering both domestic and international feed production, the total arable land dedicated to growing animal feed for the EU declines by 49% (Figure 5 and Chapter 4.5).

42 The ten most promising greenhouse gas mitigation technologies or practices are analysed. Six are **modelled** in CAPRI (anaerobic digestion, nitrate feed additive, linseed-oil feed additive, low protein feeding, anti-methanogen vaccination and breeding for ruminant efficiency) and four are **calculated** based on the literature and integrated into our scenario with an optimistic adoption rate of 50% (methane-inhibiting feed additives, manure acidification, slurry removal/cooling and nitrification inhibitors).

43 The low and high range for mitigation potentials were estimated based on a 25% and 75% adoption rate for the four calculated technologies. The modelled mitigation technologies depicted in CAPRI remained constant.

44 Grass silage is a type of forage made from fresh grass and other grassland species that is cut, wilted and preserved through a process called ensiling, which involves storage in a silo or similar container to ferment, resulting in a preserved feed.

Ruminants

Permanent grassland covers about one third of the utilised agricultural area in the EU both in 2020 and 2045. Utilising grassland biomass as feed for ruminants reduces land competition with food crops and supports ecosystem services (Windisch 2021, Poux & Aubert 2022, Dondini et al. 2023). However, increasing forage in ruminant diets can lead to increased methane emissions and reduced feed efficiency, depending on the organic matter digestibility of the plant biomass (Vargas et al. 2022, Wróbel et al. 2023). Although environmental conditions and species composition significantly influence the digestibility of organic matter, well-managed grasslands can achieve digestibility levels close to concentrate feeding (Loza et al. 2021).

Grazing plays a crucial role in enhancing animal welfare and grassland management (Grodkowski et al. 2023, Wróbel et al. 2023), as well as biodiversity preservation when managed in a more sustainable way. The reduced livestock population facilitates more grazing and grassland feeding by 2045. Grazing contributes to animal welfare, biodiversity and other ecosystem services. These include better soil-nutrient cycling and fire control (Ascoli et al. 2023, Milazzo et al. 2023). The average dry-matter share of permanent and arable grass in dairy-cattle feed increases from 53% to 57%. Regions with large areas of grassland have a higher-than-average grass inclusion, and the proportion of extensively or semi-intensively (i.e., reduced chemical inputs and fertilisation) managed grassland increases until 2045, leading to low-input systems with enhanced biodiversity.

The use of grassland for ruminants varies significantly depending on the region and year. Considering potential climate change impacts in our scenario – such as increased temperature, irregular rainfall and drought – fluctuations in forage yields are expected (Schils et al. 2022, Wróbel et al. 2023). Therefore, it is necessary to reassess feed compositions and implement adaptive storage measures to mitigate these impacts on feed supplies. Grasslands not used for feed production could be harvested for biogas production (Annex Chapter 6).

Despite increasing the average share of grass in dairy-cattle feed, the average milk yield per cow increases by about 7%, from approximately 7 200 litres in 2020 to nearly 7 700 litres by 2045. This increase is achieved through genetic improvements, as well as enhanced herd management and animal health practices. Yield improvements vary among member states, depending on their previous production methods. Milk yields decrease in highly productive regions where breeding primarily emphasised milk-production traits and energy-intensive feeding, which has enabled annual production levels of more than 10 000 litres per cow in 2020. Low input, semi-intensive grazing systems typically result in lower milk yields compared to indoor systems. However, adapted breeding and selection for genetic traits can increase resilience to environmental stressors, improve milk yields and reduce mortality for grazing cattle (Hempel et al. 2019, Vroege et al. 2023). Furthermore, adapted breeding can increase both milk and meat production in grassland-based feeding systems (McGee et al. 2024, Roche et al. 2018), thereby decreasing the need for arable land dedicated to feed production.

Grazing is a cost-efficient option to maintain permanent grasslands and grassland biodiversity. Despite lower average milk production per cow, grazing can positively impact biodiversity (Wróbel et al. 2023) and decrease the demand for feed production on arable land (Reinsch et al. 2021). Permanent grasslands are essential for climate protection due to high amounts of sequestered carbon in the soil (De Rosa et al. 2024). The carbon stock under permanent grassland is nearly double that of arable land: croplands mean stock = 47 tonnes per hectare; grasslands mean stock = 85 tonnes per hectare (European Commission 2023d). Bai & Cotrufo (2022) indicate that nearly 80% of EU grasslands have potential for increasing carbon storage in the topsoil, which can be improved by sustainable management and adaptive grazing strategies.

Infobox 5: Agricultural peatland and grazing

As part of our scenario, about four fifths of the peatlands currently used for agriculture are rewetted (Chapter 4.6) due to their significant importance in mitigating greenhouse gas emissions. Of the 2.8 million hectares of rewetted land, 57% was formerly grassland, while 43% was previously used for arable farming. The remaining one fifth of agricultural peatlands are converted to shallow-drained grasslands, allowing extensive grazing or other extensive grassland use. In peatland-rich regions, rewetting changes management and feeding practices of cattle farms. While rewetting might lead to destocking of animals in some regions, in other cases the loss of the forage due to rewetting does not result in cattle-stock reductions, but can be compensated by fodder grown on mineral soils.

We assume different grazing strategies are adopted by farmers in our scenario. This includes rotational grazing – which allows for periodic rest for vegetation regrowth – and ley farming, which involves alternating arable land with temporary pastures or fodder crops for livestock (Jordon et al. 2022, Taube et al. 2023). Such approaches reduce soil degradation, reliance on synthetic inputs and improve soil-nutrient cycling. While soil carbon sequestration in grasslands can partially offset greenhouse gas emissions from ruminants (Wang et al. 2023), the overall greenhouse gas emissions of cattle remain high. According to Dondini (2023: 26) the annual average soil organic carbon sequestration potential of European grasslands is 0.2 tonnes of carbon per hectare. Despite a reduction in cattle numbers, with a resulting 1.12 livestock units[45] per hectare of grassland in the EU in 2045, methane emissions still amount to an annual average of 1.6 tonnes of CO_2 equivalent per hectare of grassland for all cattle.

In addition to increasing the proportion of ruminants that graze, it is also feasible to provide a higher proportion of forage (i.e., fresh-cut grass, silage and hay) for indoor feeding. This approach offers both economic and environmental benefits, particularly in environmentally sensitive areas prone to degradation, nutrient leaching, heatwaves and drought. It helps to mitigate the effects of overgrazing (Akert et al. 2020) and allows for more efficient feed utilisation compared to extensive grazing (Brito et al. 2022, Hofstetter et al. 2014).

Non-ruminants

The share of agricultural by-products (e.g., oilseed meals, cereal bran and sugar-beet pulp) and animal by-products (e.g., bone/blood meal and poultry offal) in non-ruminant feed increases in our scenario. Due to the declining livestock population and feed demand, a greater proportion of livestock feed rations can be sourced from by-products. Increasing the utilisation of crop residues, food by-products and food waste reduces the use of arable land for feed production.

Current feeding practices for pigs and poultry are primarily based on arable crops. In 2001, the EU prohibited the use of feeding food residues containing traces of animal products to livestock due to concerns arising from Bovine Spongiform Encephalopathy (BSE), a neurodegenerative disease affecting cattle, which poses potential risks to animal and human health. However, food residues have been declared safe for non-ruminants, as confirmed by a 2018 risk assessment conducted by the European Food Safety Authority

45 The livestock unit is a reference unit which facilitates the aggregation of livestock across different species and ages, simplifying comparison and analysis. This is achieved with specific coefficients based on the nutritional or feed requirement of each type of animal. The reference unit used for the calculation of livestock units (= 1 LSU) is the grazing equivalent of one adult dairy cow producing 3 000 kg of milk annually, without additional concentrated feedstuffs (Eurostat 2023f).

(EFSA). This assessment reaffirms that the utilisation of processed pig protein in poultry feed and processed poultry protein in pig feed poses minimal or negligible risk (EFSA Panel on Biological Hazards (BIOHAZ) et al. 2018).

D) Enhancing animal welfare

Improving animal welfare is an important element of our scenario. This is achieved by the provision of more space, diverse environments adapted to each species, outdoor access and greater opportunities for animals to express their natural behaviours. These adaptations are in accordance with various scientific recommendations (EFSA Panel on Animal Health and Animal Welfare (AHAW) et al. 2023, WBAE 2015). In addition, enhancing animal welfare reflects the demands of EU citizens. In the Eurobarometer 2023 survey, 84% of the respondents supported higher farm-animal welfare standards (European Union 2023a). Additional surveys indicate that the public prefers more spacious living conditions for animals, the use of straw bedding and increased outdoor opportunities, especially in pastures (Spiller & Kühl 2022).

In addition to enhancing husbandry systems, it is essential to improve management practices to increase animal welfare. Resource-, management- and animal-based indicators need to be used to evaluate welfare improvements. The following points outline the most important changes by 2045:

- **Pigs** have more space and access to different climatic zones within or outside barns. Pens with outdoor runs and free-range housing are common. Housing enrichments such as straw are provided, and non-curative interventions (e.g., tail docking) are nearly eliminated. Variation in flooring systems increases hygiene and prevents injuries.
- **Poultry** have more space and access to different climate zones within or outside the barn. The barns and outdoor areas are designed to accommodate diverse behaviours and needs of poultry. Non-curative interventions (e.g., beak trimming) are no longer necessary. The practice of confining poultry in cages has been phased out.
- **Cattle** and other ruminants are fed with a higher share of grass, hay and silage. The proportion of animals having access to pasture for grazing increases. All animals have sufficient space, including access to outdoor areas, and – with very few exceptions – tethering systems are phased out. Surgical practices, such as dehorning, are performed only in combination with pain relief.

Depending on the livestock species, these changes in animal husbandry practices have different implications across member states. While current dairy-farming practices are closer to meeting these standards, significant improvements are required in the pig, poultry and beef-cattle sectors. Implementing these improvements involves substantial investment, additional maintenance production costs and trade-offs with productivity. Therefore, to improve animal welfare across all member states, an incremental approach is necessary (Chapter 4.4.4).

Besides the quality of indoor-housing facilities and management practices, animal welfare is highly intertwined with access to outdoor areas, which can vary from basic open spaces to expansive pastures. These outdoor environments allow animals to experience increased mobility and express their natural behaviours (EFSA Panel on Animal Health and Animal Welfare (AHAW) et al. 2023, Wróbel et al. 2023).

However, enhancing outdoor access for livestock brings forth challenges. This includes a higher potential for nutrient emissions, such as when animals are kept in outdoor exercise areas rather than in closed barns, as well as vulnerability to environmental hazards and wildlife conflicts. Outdoor husbandry systems can face increased risk of animal diseases, especially from vector-borne pests such as flies, ticks and mosquitoes, along with threats from large carnivores. This includes wolves, brown bears and golden jackals in southern Europe, and wolverines in northern Europe. These challenges demand both proactive disease-prevention measures and active/passive strategies to protect grazing animals from large carnivores.

By 2045, livestock farming will be more influenced by extreme weather conditions. Factors such as extreme heat, heavy rainfall and other severe weather conditions impact outdoor animal husbandry (Godde et al. 2021, Lacetera 2019), with variations in temperature and precipitation patterns having a major influence on livestock diseases (Rojas-Downing et al. 2017). Increased temperature is a critical factor for livestock production (Thornton et al. 2021), impacting reproduction, health, feed efficiency and water availability (Silanikove 2000). Furthermore, both forage quantity and quality are affected by rising temperatures, increased carbon dioxide levels and irregular precipitation. To improve animal welfare, it is essential that technology development, management practices and agricultural policies address the challenges associated with outdoor access under climate change conditions.

4.4.2 Environmental and climate impacts

Livestock farming contributes to negative environmental effects, including greenhouse gas emissions (Cheng et al. 2022), ammonia emissions (Luo et al. 2024), nitrogen emissions to water bodies and air (Rojas-Downing et al. 2017) and land-use change for feed production (IPCC 2019). In contrast, grazing ruminants can have several positive impacts on the environment, such as enhancing biodiversity, improving soil health, promoting carbon sequestration and reducing the need for chemical fertilisers by naturally cycling nutrients through the ecosystem (Wróbel et al. 2023). Our scenario addresses all these aspects.

Greenhouse gas emissions from the livestock sector decrease by about 67%, from 282 $MtCO_2eq$ in 2020 to 93 $MtCO_2eq$ in 2045. Of this reduction potential, 81% is attributed to reduced livestock numbers, while 19% is based on improvements in technology and management practices. As part of the overall reduction, methane emissions (CH_4) from ruminants and manure management decrease by 67%. This is an important contribution to climate protection in the short term, as methane has a high global warming potential but short atmospheric lifetime (Chapter 3.1).[46]

The EU total gross nitrogen balance surplus declines by 54% in our 2045 scenario compared to 2020. The reduction in total nitrogen inputs from manure is 53%. This is a result of reduced manure quantities and improved nitrogen management. Advancements in manure-processing and storage methods, along with innovations in precision fertilisation techniques, further improve nitrogen use efficiency (Chapter 4.5).

The reduction in feed demand by 46% leads to a decrease in arable land allocated to feed crops in the EU from 66 million hectares in 2020 to 34 million hectares in 2045, a decrease of approximately 49% (Figure 25, Chapter 4.5 and Annex Chapter 5).[47] Decreasing feed demand for cereals and oilseed meals further leads to a 55% reduction in feed imports, thereby reducing the arable land used to produce feed exports to the EU by 7 million hectares. This alleviates the pressure on global land resources and thus indirectly contributes to global food security, biodiversity protection and greenhouse gas emissions reductions (Kozicka et al. 2023, Rezende et al. 2023).

4.4.3 Socio-economic impacts

The average reduction in consumption of livestock products (-51% for meat, -43% for dairy products and -42% for eggs) largely corresponds to reduced production. Given the favourable climatic factors and production conditions in the EU, exports of dairy products in our scenario double by 2045. This increase in exports reflects a smaller reduction in production than in domestic consumption. On average, raw milk production decreases by 27%, egg production by 33% and meat production by 48% (Figures 20–23).

46 The Global Warming Potential over 100 years is 29.8 for fossil methane and 27 for biogenic methane (IPCC 2021: 1017)

47 The arable land allocated to cultivating the most important feed cereal-crops is reduced by 57% for wheat, 28% for barley and 44% for rye.

This presents a significant challenge for the sector, as livestock products and feed production account for over 50% of the total value of agricultural output in the EU (Eurostat 2023e, 2023g).

Such a significant reduction in animal production results in lower farm revenue as well as decreased profits in upstream and downstream sectors, including feed suppliers, processing and distribution sectors, unless countermeasures are implemented. These impacts can partially be offset through public payments provided to farmers for adhering to higher animal welfare standards or other public goods. Furthermore, new income opportunities may arise in labour- or capital-intensive agricultural production systems, such as horticultural products and new branches of energy production (e.g., solar PV). Farmers can deliver higher animal welfare standards if the increase in production costs is covered. Establishing a long-term commitment to public animal welfare payments can provide farmers with the certainty needed to invest in high animal welfare husbandry systems (Chapter 4.4.4).

Political support for the development of alternative income opportunities for farmers can relieve economic impacts on regions dependent on intensive livestock farming. However, developing income alternatives for former livestock farms within the agricultural sector is challenging. Historically, farms often turned to livestock due to poor soil quality and land availability, as livestock provided more value added per hectare. In the face of shrinking markets, some farmers may exit the sector entirely, while others pursue different options (Salliou 2023).

This trend has already been evident for a long time. Livestock production in the EU has undergone structural changes, resulting in more animals per farm, fewer farms overall and a decrease in the number of slaughterhouses. Between 2010 and 2020 the number of farms with livestock decreased by about 40%, or 2.6 million livestock farms (Eurostat 2023a). It is likely that this trend will be enhanced due to a shrinking market and policies that incentivise investments in higher animal welfare standards.

4.4.4 Policy options

For EU livestock farming to significantly contribute to societally agreed sustainability objectives, a broad policy mix is needed. This should include strong regulations, long-term financial incentives, consumer policies and the creation of economic opportunities (Chapter 5.5). In this chapter, we outline key EU-level policies designed to support the livestock sector's contribution to our scenario.

The reduction in livestock numbers is primarily due to decreased consumption of animal products. Lowering consumption levels is the most practical approach to reduce the environmental impact of livestock production without externalising negative environmental effects to other countries through imports. For more details on food policy see Chapter 4.3.

Two policy areas are essential for advancing the livestock sector toward greater sustainability:

A) Policies to reduce negative environmental and climate impacts
B) Policies to increase animal welfare

A) Policies to reduce negative environmental and climate impacts

Outlined below are key EU policy measures and instruments aimed at supporting environmentally and climate-friendly practices in livestock farming.

Integrating emissions from livestock into carbon pricing

The current policy environment does not provide sufficient incentives to reduce greenhouse gas emissions from livestock husbandry. In particular, member states have not yet implemented policy instruments, such as taxes, to increase the relative price of animal-based products compared to plant-based alternatives.

The most important gases emitted from livestock production systems are methane, nitrous oxide and ammonia (Chadwick et al. 2011). Methane emissions mainly come from enteric fermentation in ruminants and from manure management. In addition, nitrogen surpluses, particularly in animal-dense regions, result in nitrous-oxide emissions. Implementing taxes on nitrogen surpluses based on farm-level nitrogen balance sheets, or incorporating them into an Emissions Trading System (ETS), could effectively incentivise the reductions in gross nitrogen surplus.

Overall, the inclusion of emissions from the livestock sector at farm level into an ETS for agriculture and agricultural peatlands holds the potential to incentivise the mitigation of greenhouse gas emissions in the livestock sector (Chapter 5.1). Such a market-based approach can contribute to planning security for farmers by defining a long-term pathway for the caps on the annual emission allowances. This has the potential to accelerate the adoption of more sustainable management practices and the uptake of innovation for emissions reductions. It can also induce a reduction in livestock numbers due to increasing production costs. Furthermore, the prices of animal products would increase, incentivising lower consumption patterns.

However, integrating livestock emissions at the farm level into a trading scheme entails transaction costs, which presents a challenge given the large number of livestock farms in the EU. To address this, coping strategies may involve establishing participation thresholds for farms and using standardised emissions factors per animal. Standardised emissions factors could be adapted according to management practices and applied technologies, such as pasture-based husbandry or feed additives.

Emission allowances could be distributed to farmers under different conditions. First, allowances may be allocated to livestock farmers at no cost ("grandfathered"), which can be based on historical production levels, such as average emissions from the last decade. The level of ambition set for the agricultural sector for mitigating greenhouse gas emissions would determine the annual reduction in allowances. Under increasing scarcity of allowances, farmers would have the possibility a) to buy additional allowances, b) to reduce livestock numbers, or c) to use greenhouse gas mitigation technologies. Second, farmers may be required to purchase the allowances, directly leading to increasing production costs. For example, a study indicates that a carbon price of 100 euro per tonne CO_2 in Germany would lead to an approximate 15% increase in production costs for beef and milk at the farm level (Isermeyer et al. 2019: 5).

Higher production costs would result in higher consumer prices within the EU only if these cost increases are not offset by a reduction in imports from countries without carbon pricing mechanisms. Including certain animal products in a Carbon Border Adjustment Mechanism (CBAM) would counter this effect. One option to limit transaction costs and conflicts with trading partners would be to include only the most greenhouse gas intensive livestock products, such as milk powder, beef and butter.

Industrial Emissions Directive

An existing approach to reduce emissions from livestock is the Industrial Emissions Directive (2010/75/EU). While this directive primarily targets emissions from industrial facilities, it also includes large poultry and pig farms. The purpose of the directive is to reduce emissions from nitrogen oxides, ammonia, methane, carbon dioxide and mercury. Regulations under the directive aim at reducing the environmental impact from livestock farming, particularly concerning air quality. Mandated facilities are required to obtain a permit obliging them to either prevent or reduce emissions into the atmosphere, water and soil. These permits are based on the EU's best available techniques adopted by the European Commission. Agricultural best available techniques include many aspects, such as barn construction, manure-treatment protocols and filtration systems.

The directive has been revised in 2024. From 2030 onwards, it will apply to farms with more than 280 livestock units (fattening poultry) and 350 livestock units (fattening pigs), with exceptions for extensive and organic farms. Cattle farming was proposed to be included in the directive, but so far has not been incorporated.

The next opportunity for potential changes will be the review of the directive following an assessment report scheduled for 2026 (Directive (EU) 2024/1785). The review has the potential to include a larger number of livestock farms and improve environmental impacts. This can be achieved by lowering livestock unit thresholds for livestock farms and including cattle. To prevent the directive from compromising animal welfare objectives, it is important to define best available techniques in a way that considers different husbandry conditions, such as open and free-range animal husbandry practices.

Common Agricultural Policy

The EU Common Agricultural Policy (CAP) has the potential to promote climate-friendly technologies and practices for livestock farming across both of its current pillars. Some member states have already implemented measures to promote sustainable livestock farming through their CAP Strategic Plans. For example, Luxembourg has dedicated funds to reduce greenhouse gas and ammonia emissions from beef and veal production (European Commission 2023a). Greece aims to improve grazing land in areas at risk of desertification, while Flanders (Belgium) is supporting cattle farmers to implement feeding measures to reduce enteric methane emissions (European Commission 2023a). Incentives for outdoor livestock rearing and extensive grazing practices could be expanded in a future CAP where payments are more closely aligned with environmental, climate and animal welfare goals (Chapter 5.2). Funds could also be allocated to adapt grazing-management strategies and enhance herd-protection measures.

B) Policies to increase animal welfare

This section outlines policies to improve animal welfare in the EU. Our scenario includes more space, diverse environments, increased outdoor access and greater opportunities for animals to express their natural behaviours. This can be achieved through improved legislation, public payments and consumer policies that support the demand for animal welfare-friendly products. Some of the policies, such as labelling or animal welfare payments, can be initiated through pilot programmes in member states willing to participate, with the option of expanding to a comprehensive EU-wide implementation in the medium term.

Legislation

Recent evaluations by the European Food Safety Authority (EFSA) find that existing EU animal welfare legislation no longer meets the required welfare standards (EFSA 2023). To address societal expectations on ethical concerns and sustainability challenges, the current EU animal welfare legislation needs to be updated in line with scientific evidence. The Fitness Check of the EU Animal Welfare Legislation revealed that there are gaps in the legislation, such as the inclusion of dairy cows (European Commission 2022b). The EFSA recommendations are clear about the legislative needs for animal welfare improvements. Phasing out cages for poultry, prohibiting mutilation practices and the killing of day-old chicks, improving on-farm husbandry conditions and implementing stricter import requirements need to be addressed. Furthermore, regulatory gaps for different species must be dealt with, for example regarding the protection of dairy cows, turkeys and rabbits.

Updating the EU legislation on animal welfare is important to avoid unfair competition caused by varying standards across member states and to improve animal welfare throughout the EU. The absence of updates to EU animal welfare legislation for over a decade has led some member states to implement national measures that exceed EU requirements. For example, beak-trimming has been banned in Finland since 1996. Sow stalls and farrowing crates have been banned in Sweden, and the use of cages for turkeys, ducks and geese is illegal in Poland. Enriched cages for laying hens have also been banned in Austria and Luxembourg (European Commission 2022b).

The current legislation consists of a general directive on the protection of farmed animals (Directive 98/58/EC) and four directives laying down minimum standards for the protection of laying hens (Directive 1999/74/EC), broilers (Directive 2007/43/EC), pigs (Directive 2008/120/EC) and calves (Directive

2008/119/EC). Regulations also control the transport of animals and humane treatment of animals during slaughter. As part of the Farm to Fork strategy of 2020, the European Commission committed to revising this legislation and proposed a timely revision to enhance animal welfare throughout the EU (European Commission 2021a). The animal welfare revision, planned by the European Commission, included a package of four pillars: 1) the welfare of animals at the farm level, 2) time of transport, 3) slaughter and 4) a voluntary European label for animal welfare. The European Commission has yet to propose the entire package, apart from a proposal for a regulation on the protection of animals during transport (European Commission 2023j). However, this revision process is still at an early stage.

With more free-range farming in our scenario, the threat from large carnivores (i.e., wolves, bears, wolverines, golden jackals and other predators) is expected to increase. There is already a need to strengthen protective measures for grazing animals and reevaluate the management of large carnivores. The EU can co-finance programmes for herd protection through strategies such as robust fence infrastructure, night pens and designated calving pastures. While herd-protection strategies can be effective, wildlife conflicts are likely to increase in the future. Therefore, it may be necessary to reexamine regulated hunting of large carnivores in targeted regions, such as distinct pasture landscapes or dyke areas. To achieve this, a clear target must be set for population management. This can be facilitated by adjusting the protection status of large carnivores based on close monitoring mechanisms. In the long-term, the aim should be to manage their population similarly to other hunted species.

Public funding

Improving animal welfare results in additional production costs. The potential to cover these costs through private labelling and market initiatives is limited. If the EU wants to improve animal welfare on a large scale, this cannot be achieved by tightening legislation alone. Raising animal welfare standards without border adjustments could undermine the competitiveness of EU farmers compared to countries with lower animal welfare standards, potentially leading to higher imports. Animal product imports would be difficult for the EU to regulate, given its limited ability to enforce animal welfare standards in other countries. This would ultimately counteract animal welfare goals.

Public payments for farmers who increase their animal welfare standards can cover the additional cost of animal welfare. This can alleviate the financial burden of implementing improved husbandry conditions and secure the competitiveness of EU farmers against animal products from third countries with lower animal welfare standards. Money from the CAP can be used for enhancing animal welfare in the member states. During the last CAP funding period (2014–2020), 15 European regions and 14 member states offered explicit support programmes to increase animal welfare. Public expenditure through CAP funds and national or regional co-financing amounted to 360 million euro per year for animal welfare initiatives. In the current funding period (2021–2027) member states have demonstrated greater ambition for animal welfare in their strategic plans, aiming to support at least 23% of EU livestock units with an annual budget of 900 million euro (European Commission 2023o: 11). Since the beginning of 2023, eco-schemes under the first pillar allow for the promotion of animal welfare. The transition towards improved husbandry conditions can be further strengthened if member states seize this opportunity. For example, sustainable grazing might increase production costs due to intensive management practices and lower yields. To compensate for this gap, the EU can offer CAP payments to farmers who are moving towards grazing practices or grass-based feeding under the second pillar or as an eco-scheme.

The funding currently allocated under the CAP to support the transition to higher animal welfare remains insufficient. We estimate the annual budget required for EU-wide animal welfare payments to range between 10 and 20 billion euro, which would cover the full cost of improving animal welfare.

This amount would be sufficient to address various aspects of animal welfare for beef and dairy cattle, pig fattening, poultry fattening and laying hens (Annex Chapter 5 for the calculation). Key cost drivers for improved animal welfare include increased space requirements, enhanced animal health monitoring, provision of enrichments (i.e., additional litter and other organic materials) and access to outdoor areas. The percentage increase in costs varies between livestock species, ranging from 6% to 14% for beef and from 22% to 36% for pig fattening.

Animal welfare payments should consider the unique circumstances of member states. In regions characterised by intensive livestock farming, support could be directed towards retrofitting barns to provide outdoor access for livestock and pay for higher management costs. Conversely, member states with mountain regions could grant payments to promote extensive grazing practices, which are vital to protect biodiversity, reduce erosion and conserve watersheds.

Allocating public funds for such a transformation requires societal and political acceptance. One option to uphold higher animal welfare standards without relying on public payments would be to introduce border adjustments, which would require imported products either to comply with EU standards or being subject to compensatory tariffs, compensating for the cost advantage of a lower animal welfare level. Such an approach, however, would most probably face opposition from trading partners and could be questioned under World Trade Organization (WTO) trade rules.

Improving animal husbandry requires intensive discussions with all relevant stakeholders to develop collaborative, outcome-driven solutions. Germany provides an insightful example, as there has been intensive dialogue about the transformation of livestock farming for over a decade. The current discussion is centred around a strategy developed by a commission composed of diverse stakeholders.

The strategy envisions a stepwise enhancement of minimum animal welfare standards, coupled with financial support for investments and the partial compensation of recurrent animal welfare costs. Following Germany's political reluctance to fund payments directly from existing public budgets, proposals for levies or taxes on animal products are being discussed as an indirect funding opportunity. The concept and the processes – based on labelling, public payments and levies on animal products – may act as inspiration for other member states and for the formulation of EU policies.

Finally, public funds are necessary to support the shift of livestock farms to alternative economic activities that involve fewer or no animals. Diversification programmes at both regional and national levels are an option. Member states could establish such programmes as part of their agricultural and economic policies and in the context of a European Rural Deal (Chapter 5.5).

We expect that the decreasing demand for animal products, as well as increasing environmental and animal welfare requirements, will lead to decreasing animal production, eliminating the need for explicit livestock-reduction policies at the EU level. Nevertheless, policy measures may be necessary in certain member states to accelerate reduction efforts in regions with high livestock concentrations and significant environmental impacts.

Consumer policies

Sector-based labelling systems for animal welfare by retail, processing industries and national authorities have been initiated in some member states, including the Netherlands, Denmark and Germany. While such labels provide transparency and can enable consumers to make informed decisions, they are insufficient to drive large-scale changes in animal welfare. Research has demonstrated that individual changes in purchasing behaviour do not sufficiently support a sector-wide increase in animal welfare standards (Spiller & Kühl 2022). This evidence is also highlighted in the attitude-behaviour gap, which describes the difference between the willingness to pay a higher price[48] and actual purchasing behaviour (Gorton et al. 2023). Nevertheless, voluntary labelling systems can act as a stimulus and could be implemented at the EU level. Such systems could evolve into a mandatory system encompassing imported goods at a later stage. Ideally, animal welfare labelling would be integrated into food labelling, forming part of a harmonised nutrition and sustainability labelling framework for food products (Chapter 4.3).

4.5 Arable farming

4.5.1 Scenario

Arable farming must become more environmentally friendly while meeting the growing demand for food and biomass and providing farmers with decent incomes. To achieve this, trade-offs between and within economic, social and environmental objectives have to be balanced and synergies tapped.

Beyond commodities, farmers provide a wide range of services on their land. Maximising just one of these services jeopardises the provision of the others. Our scenario entails multifunctional arable farming that is productive under variable environmental conditions, while helping to stabilise ecosystems. We reflect shifts in demand for arable products and services: more plant-based food, renewable energy and biomass for a growing bioeconomy will be produced on arable land. As part of the scenario, arable farmers use fertilisers and plant protection products more efficiently, maintain soil fertility and promote biodiversity. This is a challenge, but it also opens up opportunities for arable farming in the EU.

Multifunctional arable farming is both knowledge- and technology-intensive. It is therefore important to facilitate access to training, advice and innovation. Farmers need scope to try out new production methods and technologies and to proactively develop site-adapted solutions and new income prospects for their farms.

The scenario includes the following elements for arable farming:

A) Optimising nutrient management
B) Maintaining and restoring soil health
C) Diversifying agricultural landscapes and reducing the use and risk of plant protection products
D) Fostering the anaerobic digestion of agricultural residues, municipal waste and biomass from landscape conservation
E) Strengthening the domestic production of pulses, fruits and vegetables

We first explain how we operationalise and implement these aspects in our scenario and how this would improve the environmental performance of arable farming in the EU. We then summarise the aggregated effects on cultivated area, yields and trade balances. In Chapter 4.5.3 we discuss EU policy options to incentivise and support the changes outlined in the scenario.

A) Optimising nutrient management

In our scenario, fertiliser use is closely aligned with the nutrient requirements of crops. Nutrient losses are reduced through both technological and cropping measures. Fertilisation is carried out according to the so-called 4 R strategy, which entails the application of fertilisers at the right rate, with the right type, at the right time and the right place (de Vries et al. 2022).

Avoiding unproductive nitrogen surpluses and reducing emissions of reactive nitrogen compounds is among the most important agri-environmental measures, as nitrogen pollution contributes to the exceeding of almost all planetary boundaries (Sutton et al. 2021). Therefore, our focus is on improving nitrogen use efficiency, defined as the ratio of crop nitrogen uptake to available soil nitrogen. The higher the ratio, the better the nitrogen use efficiency.

48 According to the Eurobarometer survey of 2023, 60% of respondents expressed a willingness to pay a premium for products originating from animal welfare-friendly farming systems (European Union 2023a: 8).

In our analysis, we reduce gross nitrogen balance[49] surpluses in the EU according to the approach of Barreiro-Hurle et al. (2021). We apply progressive reduction factors to 2020 NUTS-2 regional surpluses. We do not further reduce annual regional surpluses below 25 kg nitrogen per hectare. We reduce surpluses between 25 and 150 kg nitrogen per hectare in tranches (Annex Chapter 6). We cut surpluses beyond 150 kg nitrogen per hectare by 100%. Regions with a higher gross nitrogen balance surplus in the reference year 2020 must thus make larger cuts. Nevertheless, our analysis does not level out regional surpluses; regions with higher surpluses in the reference year 2020 also show higher surpluses in the target year 2045 – but at a significantly lower level. The maximum possible gross nitrogen balance surplus on NUTS-2 level is 81 kg nitrogen per hectare per year (Figure 25).

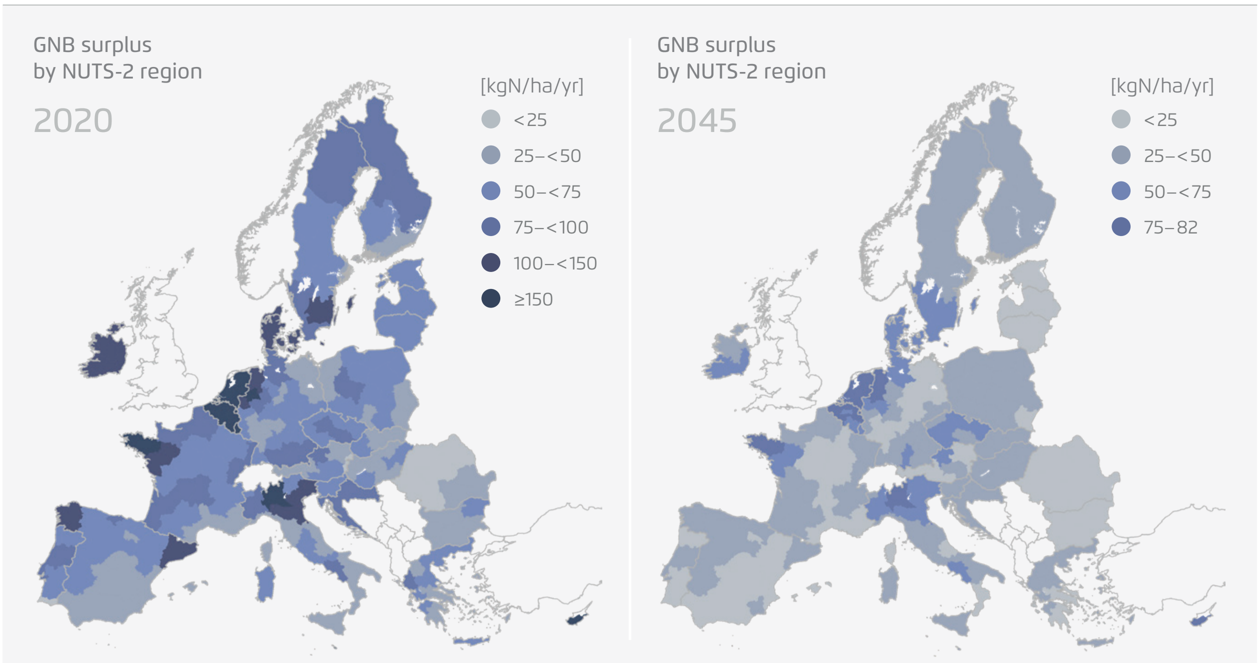
The implemented reductions stimulate the uptake of measures and technologies that improve nitrogen use efficiency in arable farming. This includes precision farming, variable rate technology, better timing of fertilisation and enhanced-efficiency fertilisers.[50]

The EU total gross nitrogen balance surplus declines by 54% in our scenario compared to 2020. The application of synthetic nitrogen fertilisers is reduced by a total of 43%. The reduction in total nitrogen inputs from manure is 53%. The decline in nitrogen inputs is due to technological measures to improve nitrogen use efficiency, but also due to the increase in unfertilised agricultural land. Unfertilised agricultural land increases by 150% (Section C and Chapter 4.2) and includes rewetted agricultural peatlands, fast-growing trees and semi-natural landscape features. The EU average reduction of total nitrogen input is 25% on productive arable land, 10% on vegetables and permanent crops and 29% on permanent grassland. The reduction in nitrogen fertiliser input translates into a 39% reduction of nitrous oxide (N_2O) emissions from mineral agricultural soils.

49 The gross nitrogen balance is calculated from the total nitrogen inputs minus total nitrogen outputs to the soil.

50 For details on the costs and impacts of the respective technology options, see Pérez Domínguez et al. (2020).

EU Gross Nitrogen Balance (GNB) surpluses in 2020 and 2045 → Fig. 25



Agora Agriculture based on CAPRI results

Since 1990, nitrogen use efficiency in EU agriculture has improved significantly. However, at present, only about 60% of the nitrogen applied to agricultural land is taken up by the crops, with the remainder being lost to connected ecosystems (Leip et al. 2011, EEA 2019b). Ecosystems have very different sensitivities to inputs of reactive nitrogen compounds. Even small excesses of nitrogen can lead to environmental damage. Differentiated reduction targets and measures are therefore required depending on the respective site conditions (de Vries et al. 2021, Schulte-Uebbing & de Vries 2021).

Nitrogen balance surpluses are particularly high in regions with high livestock densities and a high proportion of imported feed (EEA 2019b). However, high nitrogen balance surpluses can also occur in arable farming, and especially in vegetable growing (Tei et al. 2020). In order to improve nitrogen use efficiency, both the nitrogen inputs and the nitrogen outputs can be addressed. Reducing nitrogen inputs is not recommended in all EU regions to reduce balance surpluses. De Vries et al. (2021) and Schulte-Uebbing and de Vries (2021) find large potentials to close yield gaps[51] by increasing nitrogen offtake (yields) while maintaining or even increasing the level of nitrogen inputs, especially in Eastern Europe (Schils et al. 2018).

The prerequisite for low-loss plant nutrition is consistent nutrient balancing and fertiliser planning. Keeping an eye on nutrient synchronisation is also important. This requires nutrient management with high spatial and temporal resolution and close-meshed monitoring of soil mineral nitrogen. Crop rotation and variety selection, soil tillage and seeding, fertiliser choice and application must all be aligned, which is challenging for farmers operating in highly volatile commodity and input markets and under changing environmental conditions.

Nutrient losses during and after fertilisation can be largely avoided by technological measures (Oenema et al. 2009, Mahmud et al. 2021). Equally important is a site-adapted crop rotation and targeted utilisation of pre-crop effects. Nitrogen losses after the harvest of the previous crop can be reduced by establishing catch and undersown crops that permanently cover the soil and retain nitrate that is prone to leaching (Vogeler et al. 2022). There are also promising approaches in the breeding of crop varieties that maintain high nitrogen use efficiency even under unfavourable environmental conditions (Laidig et al. 2024, Lammerts van Bueren & Struik 2017).

Besides nitrogen, the macronutrients phosphorus, potassium, calcium, magnesium and sulphur, as well as microelements, are indispensable for all plant species. If only one of these nutrients is in deficiency, the genetically fixed yield potential of the crop cannot be fully realised. The mining, production, processing, use and discharge of these nutrients can also cause environmental damage and require specific precautionary measures (de Vries et al. 2022).

B) Maintaining and restoring soil health

In the overlap between lithosphere, biosphere, atmosphere and hydrosphere, soil is the basis of all terrestrial life. Soils provide indispensable ecosystem functions and services, which are also used directly and indirectly by humans (Adhikari & Hartemink 2016). Healthy soils filter groundwater, regulate the nutrient, carbon and pollutant cycle and serve as habitat for animals, plants and microorganisms.

Soil organic matter, and hence soil organic carbon, plays a vital role in maintaining and improving biogeochemical properties and processes, and is therefore considered a key indicator for soil health (Lorenz & Lal 2016). Beyond its importance for climate change mitigation, successful soil organic carbon management has numerous benefits for arable farming: higher soil organic carbon contents contribute to water retention and availability, nutrient retention and turnover, soil structure, microbial activity, degradation of pollutants and pest control.

51 The yield gap of a crop grown in a certain location and cropping system is defined as the difference between the yield under optimum management and the average actual yield produced. Yield under optimum management is defined as potential yield under fully irrigated conditions or water-limited yield under rainfed conditions (van Ittersum & Cassman 2013: 2).

Conserving and building up soil organic carbon are therefore at the heart of climate adaptation and sustainable arable farming (McGuire et al. 2022).

For 2045, we assume that soil organic carbon stocks in cultivated arable soils remain constant, which in practice implies great and targeted efforts in crop-rotation design, recycling of plant residues, soil tillage and fertilisation. For example, the cultivation of catch and undersown crops must be significantly expanded so that arable soils are covered with living vegetation as much as possible throughout the year (Poeplau & Don 2015, but see Chaplot & Smith 2023). Crop rotations must be targeted to increase soil rooting, since organic carbon from roots and root exudates contributes particularly effectively to the build-up of soil organic carbon (Poeplau et al. 2021). In particular, the integration of perennial legume-grass mixtures such as clover-grass into arable crop rotations is beneficial for the humus balance, for groundwater protection and for phytosanitary reasons (Taube et al. 2023, Weißhuhn et al. 2017, Johnston et al. 2017). Reduced, non-inversion tillage and no-till systems only minimally impair soil structure, leave a protective mulch layer on the soil surface, and thus reduce soil erosion by wind and water (Holland 2004). Soil compaction caused by the use of heavy machinery and inadequate soil management should be reduced. The carbon bound in plant residues should be consistently returned to the fields, either as green manure or after anaerobic digestion (Section D).

Beyond maintenance, we consider it unrealistic that the soil organic carbon stocks of cultivated arable soils across the EU can be increased substantially and permanently under the conditions of advancing climate change (Riggers et al. 2021, Don et al. 2023, Basso et al. 2018). We are cautious about the potential of direct biochar application on arable soils to increase soil organic carbon stocks due to the high costs of high-quality biochar and the increasing cross-sector competition for agricultural and forestry biomass (Bach et al. 2016, Muscat et al. 2020, WBD 2024).[52]

52 Unlike direct soil application, the use of biochar as a feed additive (Man et al. 2021) or as an additive for anaerobic digestion (Hoang et al. 2022) may prove economically attractive.

We assume that negative carbon dioxide (CO_2) emissions through carbon sequestration in most mineral arable soils will be achieved exclusively through permanent land-use changes. These include the conversion of arable land to permanent grassland, the rewetting of drained agricultural peatlands, afforestation and the planting of permanent woody landscape features. In temperate climate regions, the average annual carbon sequestration rate on ex-arable grassland was shown to be as high as 0.72 tonnes of carbon per hectare after an average of 14 years of land-use change (Kämpf et al. 2016). The establishment of hedgerows on arable land in temperate climate regions was shown to sequester between 2.1 and 5.2 tonnes of carbon per hectare per year for a period of 50 and 20 years, respectively (Drexler et al. 2021). Both the planting of hedgerows and other woody vegetation on arable land, and land-use change from arable to permanent grassland can therefore contribute to carbon sequestration in agricultural landscapes while at the same time enhancing biodiversity and soil conservation (Rosenzweig et al. 2016, Biffi et al. 2022).

The contribution of permanent land-use changes to climate change mitigation is quantified in Chapter 4.1.

C) Diversifying agricultural landscapes and reducing the use and risk of plant protection products

The intensification of agriculture is one of the main drivers of biodiversity loss (IPBES 2019, Raven & Wagner 2021, Tscharntke & Batáry 2023). Biodiversity in agricultural landscapes is declining dramatically (Leopoldina et al. 2020). If this trend is to be not only slowed but halted and even reversed, the way in which many agricultural landscapes in the EU are shaped and managed will have to change (Kremen & Merenlender 2018, Rasmussen et al. 2024).

We propose a package of measures that can be expected to halt and reverse the decline of biodiversity in EU agricultural landscapes. Recognising the large and growing land use conflicts, biodiversity research in recent years has increasingly worked to prioritise biodiversity measures in agriculture according to the criterion of land use efficiency (Benton et al. 2003, Felix et al. 2022, Tscharntke et al. 2021, 2022). The central finding of this research is that a minimum provision of semi-natural habitats, small cropping units and crop diversity – always at the landscape level – are key to promoting biodiversity (Tscharntke et al. 2021, Soley & Perfecto 2021, Šálek et al. 2018). Furthermore, a reduction in nutrient pollution (Section A) and a reduction in the use and risk of plant protection products can make a significant contribution to biodiversity conservation in agricultural landscapes and beyond (Candel et al. 2023, Rigal et al. 2023). To summarise, successful biodiversity management in EU agricultural landscapes can be achieved only with a balanced combination of on-field and off-field measures (Grass et al. 2021, Tscharntke et al. 2024).

In the scenario, we:

1. Calculate the regional share of productive arable land required to provide a minimum 20% share of semi-natural habitats in agricultural landscapes,
2. Reduce the average size of plots to less than 6 hectares on the landscape level and diversify crop rotations to increase both configurational and compositional cropland heterogeneity,
3. Halve the use and reduce the risk of plant protection products.

Each of these measures is highly controversial in agricultural practice and policy debate. The need for action as well as the costs and benefits of implementation vary depending on the region, site, agricultural structure and production system. These differences must be taken into account when designing policies for multifunctional landscapes (Garibaldi et al. 2023). In high-yield regions, measures for biodiversity usually have higher opportunity costs than in low-yield regions. The implications for environmental schemes under the Common Agricultural Policy (CAP) are discussed in Chapter 5.2. The annual opportunity costs of structurally diverse agricultural landscapes in the EU in 2045 are estimated at 9–20 billion euro (Annex Chapter 6).

Restoring semi-natural habitats in simplified agricultural landscapes

In landscapes dominated by agriculture, remnants of semi-natural landscape features contribute significantly to the protection and promotion of biodiversity (Tscharntke et al. 2005). At least 20% of the area in agricultural landscapes should be covered by semi-natural features (Mohamed et al. 2024, García-Vega et al. 2024, Tscharntke et al. 2021). Below this threshold, habitat connectivity declines disproportionately (Garibaldi et al. 2021).

As part of our scenario, by 2045, around 5% of productive arable land in the EU must be provided for semi-natural features to achieve 20% semi-natural habitat cover in all agricultural landscapes. EU regions are affected to very different degrees. In many regions, the requirement of at least 20% semi-natural habitat cover in agricultural landscapes is already met. Other regions are dominated by intensive arable farming and have very few semi-natural features. There, more productive arable land would have to be provided for biodiversity conservation. At the NUTS-3 level, the range is between 0 to 17% of arable land (Figure 26).

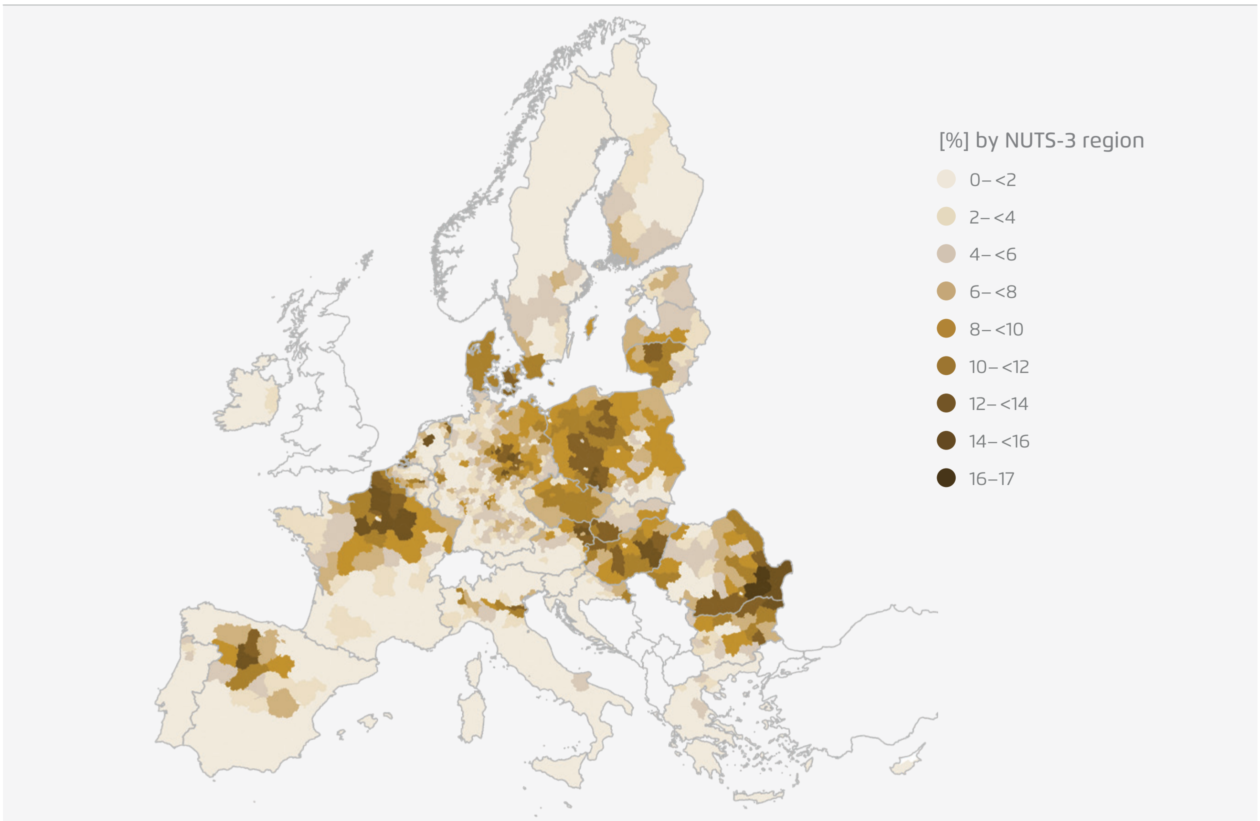
The term "semi-natural landscape features" covers both crop habitats that are farmed within the boundaries of biodiversity conservation[53] and non-crop habitats[54]. Lines of fast-growing trees for biomass production, and so-called biodiversity photovoltaics (PV)[55] can also be considered semi-natural depending on the local landscape character. Which types of semi-natural features best fulfil the local conservation purpose and provide the greatest synergies with climate, water and soil protection can be assessed only on site.

53 For example, perennial legume-grass mixtures in an arable crop rotation, extensively grazed or mown permanent grassland, agroforestry systems and plant protection product-free cereal fields with reduced crop density.

54 For example, single trees and rows of trees, hedges, fieldstone walls, flowering and buffer strips, fallow land, ditches and ponds.

55 Biodiversity PV refers to systems that, in addition to generating electricity, also implement measures to promote biodiversity. For example, the size, spacing and orientation of the solar modules are adapted compared to conventional ground-mounted PV (e.g., Blaydes et al. 2021).

Estimated share of arable land allocated to semi-natural landscape features in the EU in 2045 → Fig. 26



Agora Agriculture

In our 2045 scenario, the target is that a minimum 10% of the area in agricultural landscapes should be non-crop semi-natural features (see e.g., Oppermann et al. 2020, European Commission 2021f). To achieve this goal in all EU agricultural landscapes, a total of around 1% of arable land must be set aside. A further 4% of arable land in the EU can be farmed as semi-natural arable land or used for other productive purposes that are compatible with biodiversity conservation. In our scenario, 1.3 million hectares are planted with biodiversity-friendly fast-growing trees for biomass production. About 72 000 hectares are covered by biodiversity PV (Chapter 4.1).

When it comes to the critical question of how much of the productive agricultural land needs to be used for semi-natural features, reference to the cultivated land of individual farms falls short of the mark. The decisive criterion is the endowment of an agricultural landscape with semi-natural features. An agricultural landscape is dominated by agricultural land use, but also includes the areas adjacent to and surrounded by agriculture. The margins between the agricultural and non-agricultural land are of high conservation value and must therefore be accounted for when calculating the land requirements for semi-natural features. Farms located in agricultural landscapes with a sufficient endowment with semi-natural features do not need to designate any further land for such features.

This principle was followed in the scenario. To date, there are no comprehensive statistics on the endowment of agricultural landscapes with semi-natural features in the EU. To estimate the arable land that must be provided regionally for semi-natural features to reach 20% semi-natural cover, we use the Corine Land Cover (CLC 2018) and remote sensing data (d'Andrimont et al. 2021). The Corine Land Cover makes it possible to identify those agricultural landscapes which, by definition, have more than 20% semi-natural features. In the agricultural landscapes, which do not reach this threshold, remotely sensed woody features like hedgerows, shrubs, lines and clusters of trees are categorised as semi-natural (Annex Chapter 6).

Extensive permanent grassland is particularly valuable for biodiversity (Wilson et al. 2012). In recent decades, the EU's permanent grassland area has declined. Both intensification and abandonment threaten the multifunctionality of permanent grasslands (Schils et al. 2022). Maintaining and expanding extensive permanent grassland is vital from both a climate and biodiversity perspective (García-Vega et al. 2024, Poux & Aubert 2022, Bai & Cotrufo 2022). Accordingly, the area of permanent grassland is kept constant in our scenario, while the intensity of management is reduced. Under this condition, permanent grassland is considered a semi-natural habitat in our analysis (Chapter 4.4.1).

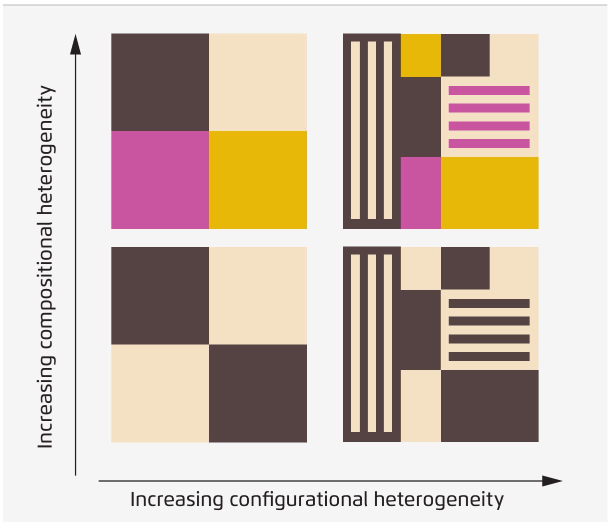
The contribution of peatland rewetting to species conservation is also taken into account in our analysis: 80% of the organic soils currently used for agriculture are rewetted in our scenario, 80% of which are used to produce biomass for the bioeconomy and the remaining 20% are wilderness and solar PV (Chapter 4.6). We consider rewetted agricultural peatlands to be contiguous landscapes in which the criterion of a 20% share of semi-natural habitat is met.

Both the successful rewetting of agricultural peatlands and the preservation of semi-natural permanent grassland thus reduce the regional need for additional semi-natural features on arable land.

Reducing the size of arable plots and diversifying crop rotations

A core tenet of landscape ecology is that spatial heterogeneity affects ecological systems. Fahrig et al. (2011) distinguish between compositional and configurational heterogeneity of landscapes. Compositional heterogeneity is the variety of production cover types and configurational heterogeneity is their spatial pattern in a landscape (Figure 27). In arable farming, increasing landscape heterogeneity translates into reducing the average size of cropping units, i.e., plots (configurational heterogeneity) and into diversifying crop rotations (compositional heterogeneity). Again, the landscape reference also applies here, not the individual farm.

The two main axes of heterogeneous agricultural landscapes → Fig. 27



Agora Agriculture based on Fahrig et al. (2011)

Small plots are favourable for biodiversity in agricultural landscapes (Clough et al. 2020, Hass et al. 2018, Gámez-Virués et al. 2015, Martin et al. 2019). Reducing the size of arable plots is not about splitting agricultural fields by integrating non-crop semi-natural features such as hedges, grassy margins, field stone walls or tree lines, but about reducing the area cultivated with one single crop. The aim is to increase crop-to-crop edge density in agricultural landscapes. An analysis of 435 North American and European landscapes found that the positive effect of decreasing plot size was particularly clear and strong when the average plot size at the landscape level fell below 6 hectares (Sirami et al. 2019).

Information on the size of cropping units in the EU is sparse. In the absence of EU-wide and methodologically consistent data on plot sizes, we cannot quantify the regional need for action. However, available data on regional plot sizes in some EU member states show that action is needed in only some of the EU's agricultural landscapes (Schneider et al. 2023b, Tetteh et al. 2021). Many EU regions already meet the recommended average plot size of below 6 hectares.

Reducing plot size is a particularly attractive measure for biodiversity, as in principle neither productive arable land nor yields are lost (Martin et al. 2019). Instead of growing crops in large plots, they are grown side by side. Nonetheless, farming large homogenous units is usually more cost- and labour-effective than farming a mosaic of plots. In many cases, however, additional labour, farm-to-field trips and land required for headlands can be significantly reduced if plots are laid out in strips as strip intercropping (Alarcón-Segura et al. 2022, Rakotomalala et al. 2023). A patch- or strip-shaped cropping system also helps to adapt to the small-scale heterogeneity of a field and can thus be economically advantageous (Rosa-Schleich et al. 2019, Li et al. 2021, Donat et al. 2022). Cost savings in crop protection are also possible, since higher crop edge density has been shown to significantly reduce pest pressure and promote beneficial predators (Chaplin-Kramer et al. 2011, Marini et al. 2023). By choosing strip widths compatible with the machinery a farmer already has, implementation of intercropping often can be realised without significant changes in equipment or management (Apeldoorn et al. 2020).

From a phytosanitary perspective, however, in strip intercropping systems, a clean and accurate adherence to crop rotation can be challenging. At least a one-year gap between neighbouring strips of the same crop is needed to avoid the risk of plant-disease transmission (Apeldoorn et al. 2020). For precise adherence to the established cultivation strips without overlapping areas, data-driven solutions such as controlled traffic farming are crucial. Crops that have very different demands, for example for primary and secondary tillage, plant protection, irrigation and harvesting, can only be poorly combined on a small scale. In the overall picture, however, there is great potential in European agriculture to reduce cropping units cost-efficiently. The prerequisite is to make innovative concepts such as "spot farming" or "strip intercropping" practicable for the breadth of arable farming (Wegener et al. 2019).

Beyond plot splitting, numerous studies prove the positive effect of a diverse crop rotation on biodiversity (Lichtenberg et al. 2017, Rosa-Schleich et al. 2019, Sirami et al. 2019). However, whether a specific crop diversification actually promotes biodiversity in a specific case depends on which crop is integrated into which crop-rotation and landscape pattern (Beillouin et al. 2021). An increase in input-intensive crops (e.g., intensive tillage, plant protection and fertilisation) can also have negative effects on the quality and connectivity of agricultural habitats (Hass et al. 2018). Furthermore, Sirami et al. (2019) show that the effect of increased crop diversity on biodiversity is contingent on the provision of semi-natural features.

Due to economic constraints, current cropping patterns in the EU often do not fulfil general principles of balanced arable crop rotations (Blickensdörfer et al. 2022). On many farms, a defined, recurring sequence of crops is missing. Instead, farmers make relatively spontaneous cultivation decisions depending on the market situation, which often leads to simplified and unsystematic cropping patterns (Leteinturier et al. 2006, Stein & Steinmann 2018).

However, general crop-rotation principles cannot be implemented in an exemplary manner everywhere in the EU. There can be no blanket recommendation for "ideal" crop rotations because each location with its unique soil, climate, weather and market conditions requires an individual solution. In our scenario, we deliberately refrain from defining rigid crop-rotation patterns (e.g., by specifying a minimum number of rotation elements or an area share of legumes), because they would inevitably reach their limits due to the different cropping conditions in the EU. Instead, in our analysis we set the model restriction, that critical acreage totals of individual crops or crop families are not exceeded at NUTS-2 level. These acreage totals are derived from crop-cultivation breaks recommended in the scientific literature (e.g., Jeangros & Courvoisier 2019)

(Annex Chapter 6). The adherence to cultivation breaks ensures that overly simplified cropping patterns are impossible.

Reducing the use and risk of plant protection products

Reducing the use and risk of plant protection products in agriculture is another key lever for overcoming the biodiversity crisis in agriculture (Candel et al. 2023, Geiger et al. 2010, Schäffer et al. 2018, Tsiafouli et al. 2015).

In our scenario, we halve the use of plant protection products following the approach of Witzke et al. (2021). This approach allows to model a gradual reduction in product use, differentiating between crops and standard categories of plant protection products, i.e., fungicides, bactericides, herbicides, insecticides, acaricides, plant growth regulators and others. We reduce the amount of products applied, taking into account the expected decrease in yields and the associated loss of farm income. For methodological reasons, our modelling does not apply any risk weighting of plant protection products, categories, or active substances (Annex Chapter 6).

In addition to reducing the amount of plant protection products in individual crops, other factors influence the extent of their use in our scenario:

- Changes in cropping patterns induced by changes on the demand side,
- Reduction of the area on which plant protection products are applied. This is induced mainly by the increase in semi-natural landscape features, fast-growing trees and by rewetting agricultural peatlands,
- Efficiency gains as an extrapolation of past trends.

The overall reduction in the use of plant protection products in our scenario is 52%. The reduction per hectare is 49% on arable land excluding vegetables and 39% on vegetables and permanent crops. The increase in area that is not treated with plant protection products explains why per-hectare reductions are lower than the overall reduction.

As part of its Farm to Fork and Biodiversity strategies (European Commission 2021f, 2022f), the European Commission has set the target of halving the use and risk of plant protection products by 2030 (Schneider et al. 2023b). This target corresponds to the Kunming-Montréal Global Biodiversity Framework that was adopted by the 15th Conference of Parties to the UN Convention on Biological Diversity (COP15) in 2022 (Chapter 3.2) (CBD 2022).

Halving the use and risk of plant protection products is a tangible political target for an ambitious reduction path. The quantitative target itself is difficult to assess from a scientific perspective, but has nevertheless found broad support in the scientific community (Candel et al. 2023).

The prerequisites for a scientific evaluation of the target would be:

- A meaningful data basis on the use of plant protection products in the EU.
- A clear set of indicators for assessing both the human and ecotoxicological risks of active ingredients, products and application patterns.

Neither basic requirement is met at the EU level (Mesnage et al. 2021, Möhring et al. 2023).

Since the adoption of the European Sustainable Use Directive in 2009, integrated pest management has been mandatory for all EU agriculture (Directive 2009/128/EC). However, a critical examination of the developments in EU arable farming in recent decades reveals that this goal has been missed (Helepciuc & Todor 2022, Lefebvre et al. 2015). The use of chemical plant protection products is often simply more cost-effective than the time-consuming mechanical weed control or preventative measures in crop rotation and landscaping. We thus see great potential for reducing the use and risk of plant protection products in EU agriculture, both through technological, data-driven innovations, and through agronomic precautions.

Depending on the respective assumptions made about a 50% reduction in plant protection products, impact assessments come to very different conclusions (Schneider et al. 2023a). With reference to suitable non-chemical crop protection alternatives, some studies come to an optimistic assessment of negative yield effects (e.g., Hossard et al. 2014, Lechenet et al. 2017), while others predict higher yield losses (e.g., Barreiro-Hurle et al. 2021, Frisvold 2019, Henning & Witzke 2021, Popp et al. 2013).

In our 2045 scenario, we assume that the amount of plant protection products applied can be reduced by 15% without negative yield effects. First, due to the diversified landscape and crop-rotation patterns implemented in our scenario: numerous studies have shown that diversified agricultural landscapes deliver significantly higher biocontrol than landscapes with low structural diversity (Ferrante et al. 2024, Rosa-Schleich et al. 2019, Thies & Tscharntke 1999). Second, due to technological innovations, for example in precision farming (Anastasiou et al. 2023), data-driven forecasting of plant diseases and pest infestations (González-Domínguez et al. 2023) and plant breeding (Komal et al. 2023).

Our assessment of the technological reduction potential is uncertain. On the one hand, we anticipate leaps in innovation in machinery (e.g., spot spraying), plant disease forecasting, new plant protection products and plant breeding. On the other hand, an increase in disease and pest pressure as a result of advancing climate change is plausible (Gautam et al. 2013, Singh et al. 2023). Based on a synopsis of the scientific literature (e.g., European Commission 2022a), we consider our assumptions on the potential of technologies to reduce the use of plant protection products to be conservative.

D) Fostering the anaerobic digestion of agricultural residues, municipal waste and biomass from landscape conservation

A key technology for reducing the environmental impact of agriculture is the anaerobic digestion of agricultural residues, organic municipal waste and biomass from landscape conservation (Dale et al. 2020, Bumharter et al. 2023). Anaerobic digestion produces biogas that can be used to generate renewable energy and substitute for combusted fossil fuels. Biogas technology has fallen into disrepute among many stakeholders because flat-rate feed-in tariffs for bioenergy from biogas have led to a sharp increase in the cultivation of energy crops with consequences for regional cropping patterns (Britz & Delzeit 2013), land rental prices (Demartini et al. 2016) and land-use change (Lüker-Jans et al. 2017). However, biogas production can make a valuable contribution to improving nutrient and carbon recycling in agriculture if it is consistently geared towards the anaerobic digestion of:

- Manure, feed residues and bedding from animal husbandry,
- Organic municipal waste (e.g., biowaste and green waste, sewage sludge),
- Crop residues from arable land (e.g., straw and haulm),
- Catch and cover crops,
- Biomass from the maintenance of semi-natural landscape features (e.g., rotational fallow and ley, field margins, riparian and buffer strips).

Biomass potentials can be distinguished according to their theoretical, technical and economic nature (Offermann et al. 2011). The theoretical biomass potential is the physical upper limit of the available biomass supply within a defined time period and space. The technical potential is lower, for example due to losses during harvesting and storage. Only a fraction of the technical potential can be mobilised economically. Bioenergy systems are considered economically viable if their specific energy costs – also influenced by political interventions – do not exceed those of conventional energy systems. The economic viability of residue-based biogas production depends on capital and energy costs, subsidies and feed-in tariffs, the opportunity cost of the investment and the availability of equipment and expertise for managing substrate mixtures, which are rich in crop residues and manure (Einarsson & Persson 2017).

We estimate the annual technical potential of agricultural residues, organic municipal waste and biomass from semi-natural features in the EU in 2045 at

625 TWh (Figure 28).[56] Straw has the highest technical potential with 171 TWh, followed by catch and cover crops with 128 TWh. Due to declining livestock numbers, the technical potential of farm manure decreases: It amounts to 92 TWh in 2045 compared to 187 TWh in 2020.

In terms of their economic potentials, biomass types must be assessed differently. Beyond energy policies, the following restrictions are particularly important (see e.g., Einarsson & Persson 2017, Scarlat et al. 2018, Bumharter et al. 2023):

- **Maximum transport distances for biogas substrates.** Each biogas plant can collect substrates only within a limited radius. Depending on the type of substrate and plant size, transport distances of between 10 and 50 kilometres are considered economically viable (Scarlat et al. 2018, 2019).
- **Sustainable removal rates of crop residues.** If it is not feasible to recycle the digestate back to the fields due to long transport distances, some of the plant residues must remain on the soil as green manure to maintain soil organic carbon stocks. Moreover, on many sites, leaving plant residues on the soil surface as a mulch layer is necessary for erosion control. Scarlat et al. (2010) estimate a maximum removal rate of 40–50% of the theoretical biomass potential from crop residues. This may be higher or lower depending on crop rotation and location.
- **Competing uses of crop residues and organic municipal waste.** Crop residues are used in agriculture as green manure, mulch, fodder or bedding, and are then not (or only partially) available for biogas production. By-products and waste from food production can be used in animal nutrition (Chapter 4.4). Furthermore, the demand for residue biomass from other sectors of the economy is growing (Chapter 4.2). These alternative industrial uses often provide higher value added, and can also be beneficial from a climate change mitigation perspective (Phan-huy et al. 2023).

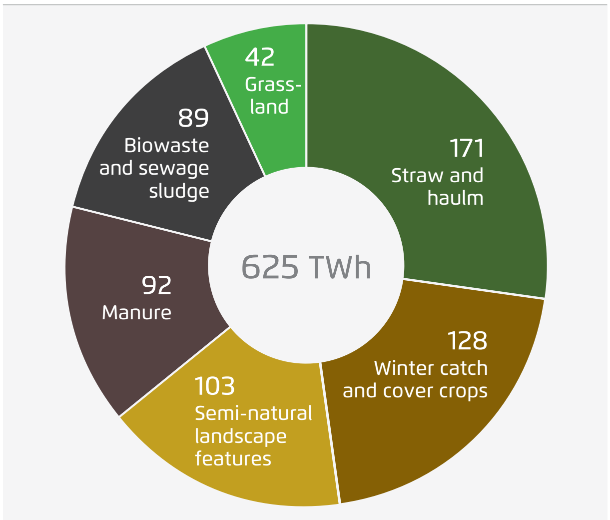
56 To calculate the theoretical and technical biomass and bioenergy potentials of our land use scenario, we use a calculation tool developed by the DBFZ which builds on the DBFZ resource data repository (Naegeli de Torres et al. 2023) (Annex Chapter 6).

Against this background, high mobilisation rates are realistic for spatially centralised substrates. This applies to biowaste, sewage sludge and other organic municipal and industrial waste. The mobilisation rate of manure depends largely on the regional substrate density, the size of the livestock facilities and the husbandry conditions. Scarlat et al. (2018) model an economic mobilisation rate of around 70% for current production patterns in EU livestock farming.

In our scenario, livestock numbers in the EU and livestock density in the hotspot regions of livestock farming decline. The animals have more space, access to outdoor areas and pasture (Chapter 4.4.1). The economic bioenergy potential from farm manure in our scenario is therefore lower than for the status quo of EU livestock husbandry. Following the method of Pérez Domínguez et al. (2020), only manure from livestock facilities with more than 200 livestock units can be digested anaerobically in our scenario, due to economical constraints. The share of manure digested anaerobically in our scenario is 13% of the total manure produced (15% of cattle manure and 68% of pig manure) and the energy yield is 13 TWh per year. We assess this

Technical bioenergy potential* of residue biomass for anaerobic digestion in the EU in 2045

→ Fig. 28



Agora Agriculture based on CAPRI results. * This includes all residue biomasses minus losses. The economic potential is lower.

as the minimum level of the anaerobic digestion of manure to be aimed for. Higher mobilisation rates can be achieved by organising manure logistics and digestate recycling across farms.

The economic potential for an increase in anaerobic digestion is lower for decentralised feedstocks such as biomass from straw, intercropping, catch crops, arable leys and semi-natural landscape features. Cereal straw, for example, is easy to transport and store, but consistent recycling of digestate from straw is unlikely with long transport distances. Moreover, there is already a high and increasing demand for straw from other sectors. The technical biomass potential of an increased cultivation of catch and cover crops in the EU is large (Magnolo et al. 2021). In practice, however, restrictions regarding seasonal water availability, harvest logistics and transport distances to the nearest biogas plant must be considered. In any case, an upscaling of the anaerobic digestion of decentralised biomasses requires the expansion of biogas infrastructure, harvesting technology, storage and pretreatment capacities and corresponding policies (Einarsson & Persson 2017). The mobilisation of these substrates will determine whether the current level of EU biogas production can be maintained and the European Commission's biomethane target of 35 billion cubic metres by 2030 (European Commission 2023d) can be achieved on a sustainable substrate basis.[57]

In addition to producing bioenergy, anaerobic digestion allows for low-loss recycling of plant nutrients and improves the efficiency of organic fertilisation. The recycling of digestate to the arable land can partially replace synthetic mineral fertilisers. Moreover, the anaerobic digestion of organic municipal waste and field application of their digestate recovers nutrients and carbon that would otherwise have left the agricultural system (Bedoić et al. 2019, Hamelin et al. 2011, Kougias & Angelidaki 2018). The anaerobic digestion of manure reduces methane and nitrous oxide emissions from manure management and improves the efficiency and hygiene of manure fertilisers (Montes et al. 2013).

57 EU biogas and biomethane production was approximately 170 TWh in 2021 (European Commission 2023m) and the energetic value of 35 billion cubic metres of biomethane is equal to 337 TWh.

In our scenario with significantly reduced numbers of ruminant livestock, anaerobic digestion offers prospects for the maintenance of environmentally valuable permanent grassland and leys. The profitability of catch and cover crops in arable crop rotations may be improved if they are harvested for anaerobic digestion. Consistent mowing and harvesting removes nutrients from semi-natural grassland, thereby increasing its conservation value. Spreading the digestate on arable land contributes both to crop nutrition and humus conservation.

Fugitive methane emissions and nitrous oxide emissions during biogas production, biogas upgrading and storage of digestate can cancel out the climate change mitigation benefits of anaerobic digestion. Reducing these losses is therefore important (Lehtoranta et al. 2024).

E) Developing and strengthening the domestic production of pulses, fruits and vegetables

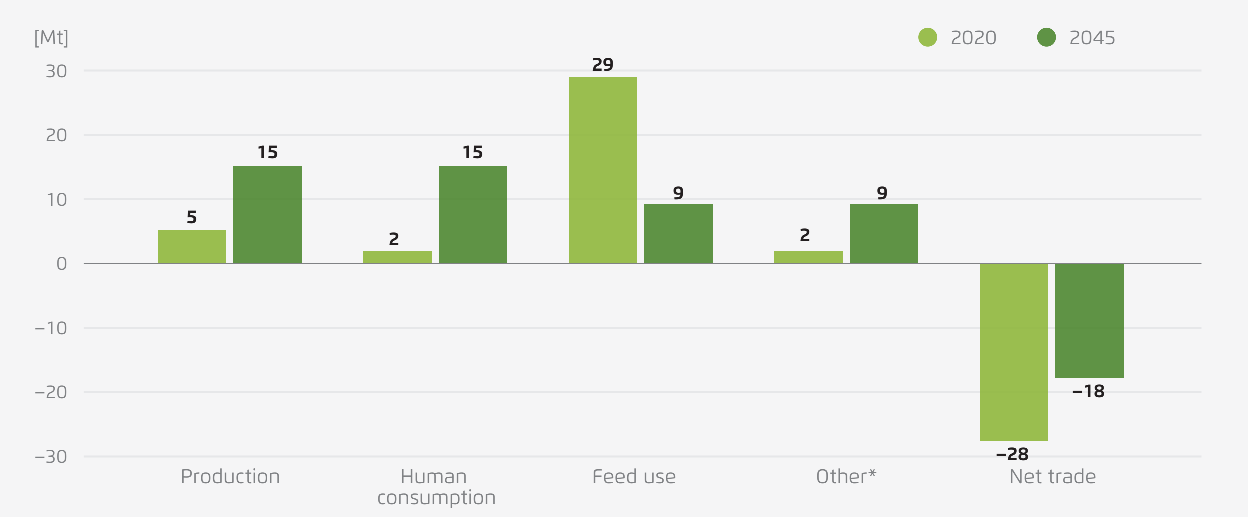
In our 2045 scenario, the annual human consumption of vegetables increases by 28 million tonnes, fruits by 27 million tonnes and pulses including soya by 20 million tonnes (Chapter 4.3). Part of this increase in demand may be met by imports, but an increase in domestic production capacity would provide economic opportunities for EU farmers due to the high added value in these production systems.[58] Accordingly, in our scenario, domestic production increases by 31% in vegetables, 53% in fruits and 187% in pulses and soya compared to 2020 (Figures 29–31).

It is not self-evident that an increase in domestic demand for fruits, vegetables and pulses will be accompanied by a substantial increase in domestic production in the EU. Increasing imports from third countries with lower environmental standards could

58 About 2.2 million hectares in the EU were used used to produce fresh vegetables in 2017, the equivalent of 1.2% of all the EU's utilised agricultural area. Almost 3.4 million hectares of land were planted with fruit, representing 1.9% of the utilised agricultural area. However, the total value of the EU's output of fruit and fresh vegetables at basic prices (i.e., including subsidies but excluding taxes on products) represented 14% of the value of all the agricultural goods and services produced in the EU in 2017 (Eurostat 2019).

Soya and pulses – EU market balances in 2020 and 2045

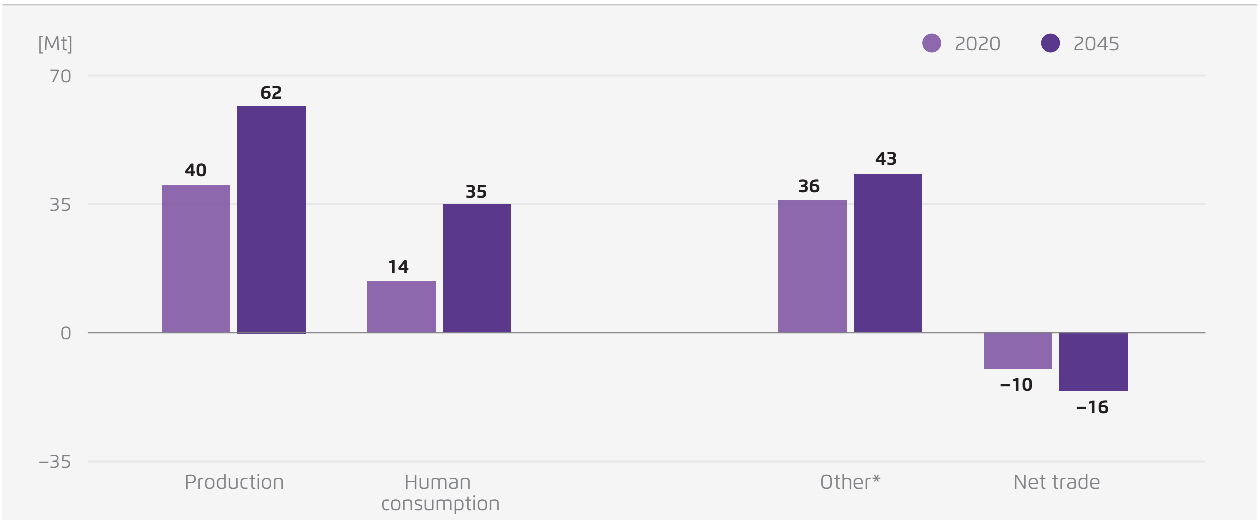
→ Fig. 29



Agora Agriculture based on CAPRI results. * Other = waste, industrial and other uses

Fruits – EU market balances in 2020 and 2045

→ Fig. 30

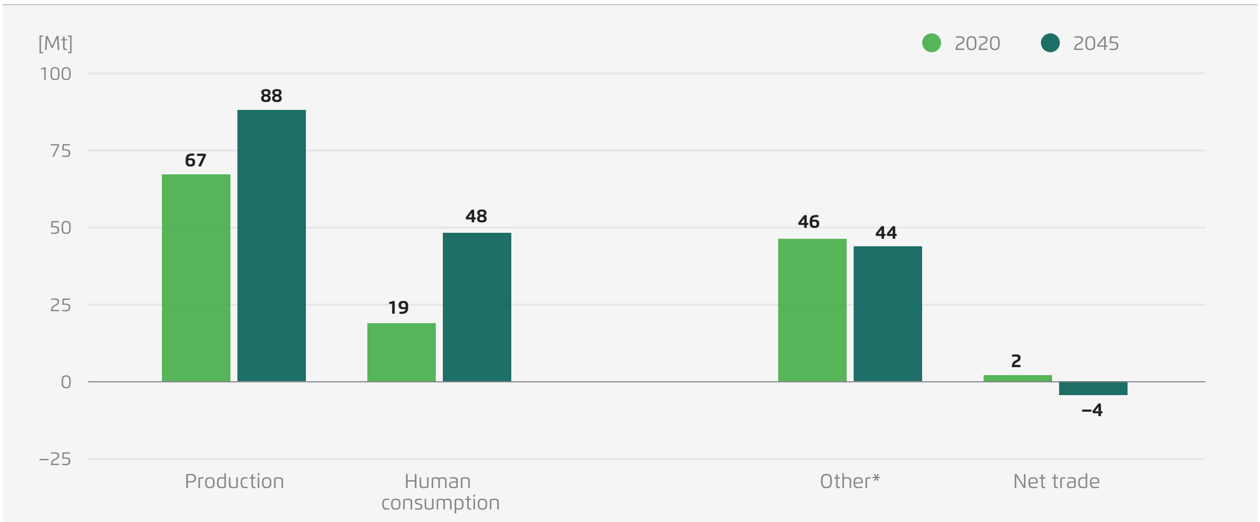


Agora Agriculture based on CAPRI results. * Other = waste, industrial and other uses

worsen the environmental footprint of fruits and vegetable consumption (Frankowska et al. 2019, Stoessel et al. 2012). The same applies to the labour conditions of fruits and vegetable production.

EU fruits and vegetable producers are in a difficult competitive position internationally. They face comparatively high labour and energy costs combined with a limited growing season (Bojnec & Ferto 2016). Moreover, EU production is under pressure to change due to increasing societal demands on nutrient management, plant protection and working conditions. Intra-EU trade and exports in fruits and vegetables are today dominated by a small number of regions that often produce fruits and vegetables in intensified and specialised production systems at comparatively low factor costs (Eurostat 2019). These production systems are criticised due to the associated environmental problems (Parajuli et al. 2019, Thompson et al. 2020), but also because of the

Vegetables – EU market balances in 2020 and 2045 → Fig. 31



Agora Agriculture based on CAPRI results. * Other = waste, industrial and other uses

working conditions of seasonal and migrant workers (Gertel & Sippel 2014). In the Mediterranean region in particular, which is (and will be) particularly hit by climate change, further growth in production capacity is questionable (Fader et al. 2016, Fraga et al. 2021, Medda et al. 2022). Leaps in technology and capacity building are needed to ensure that an increase in European fruits and vegetable production does not counteract environmental and social policy objectives. On the supply side, advances in horticultural nutrient management, plant protection, greenhouse heating, robotics, the avoidance of food losses on the field and during harvest, and sustainable irrigation are key (Bisbis et al. 2018, Incrocci et al. 2020). On the demand side, political incentives for sustainable public food procurement must be created (Chapter 4.3).

4.5.2 Environmental, climate and economic impacts

In our scenario, we assume a significant shift in demand towards plant-based and away from animal-based products – which moreover are produced on a changed feed basis. We also anticipate that society's demand for the provision of environmental services from arable farming will increase, particularly with regard to climate change mitigation and biodiversity conservation. Stricter requirements for nutrient management and plant protection influence the relative profitability and competitiveness of cropping systems. In some regions, the need for peatland rewetting requires new agricultural production methods such as paludiculture and the development of new value chains. Last but not least, the cross-sectoral challenge for full defossilisation will lead to an increase in demand for biomass and plant-based carbon, which will be met to a large extent from arable land.

All this will shape the environmental impact of EU arable farming, cultivation patterns and future market balances:

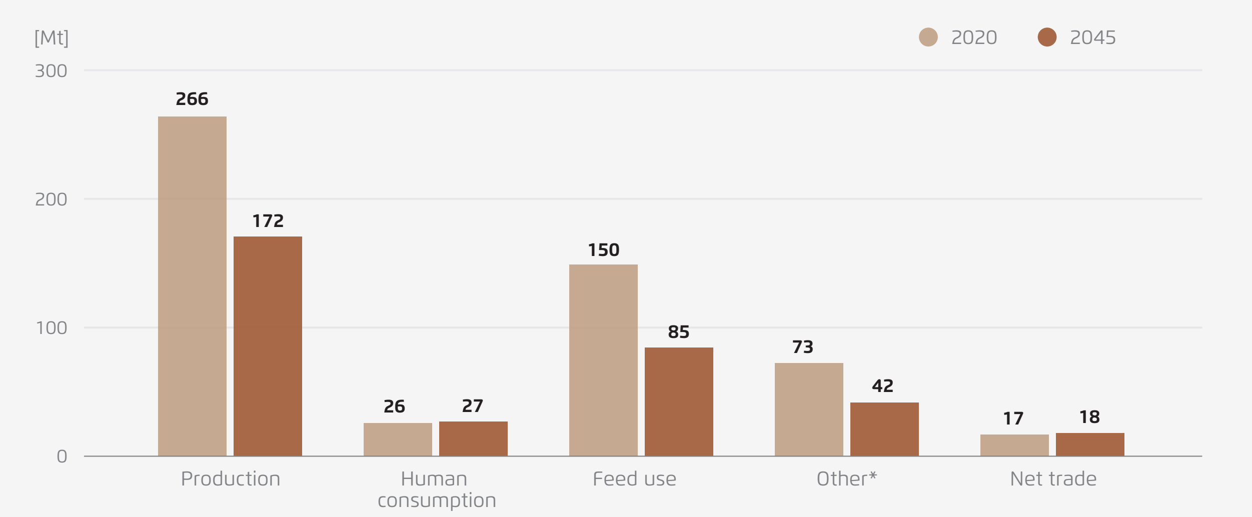
- The total nitrogen balance surplus in EU agriculture decreases by 54% by 2045 compared to 2020 and then amounts to an average of 33 kg nitrogen per hectare per year (Section A in Chapter 4.5.1).
- Nitrous oxide emissions from agricultural soils decrease by 39% and will amount to 47 $MtCO_2eq$ in 2045 (Section A in Chapter 4.5.1).
- The decline in soil organic carbon stocks in cultivated arable soils is being halted. Rewetting agricultural peatlands on former arable soils alone saves about 35 $MtCO_2eq$ emissions per year (Annex Chapter 7).
- The loss of biodiversity in agricultural landscapes is being halted and reversed. Agricultural landscapes are being diversified: Agricultural landscapes in

the EU reach at least 20% semi-natural habitats by 2045. Around 5% of arable land will be needed for this in 2045. On average, farmers cultivate small fields of under 6 hectares with a diverse crop rotation. The overall use of plant protection products declines by 52%, though the decline is smaller for fruits and vegetables.
- Cultivation patterns in EU arable farming change in our scenario. The cereal acreage declines by 26% – driven mainly by the lower demand for animal feed (Figure 32). Oilseed production remains steady (Figure 33). The production of vegetables, fruits and pulses increases (Section E in Chapter 4.5.1).

Overall, we expect crop yields to increase. In view of the advancing climate change and soil degradation, an increase in crop yield per hectare may

Cereals – EU market balances in 2020 and 2045

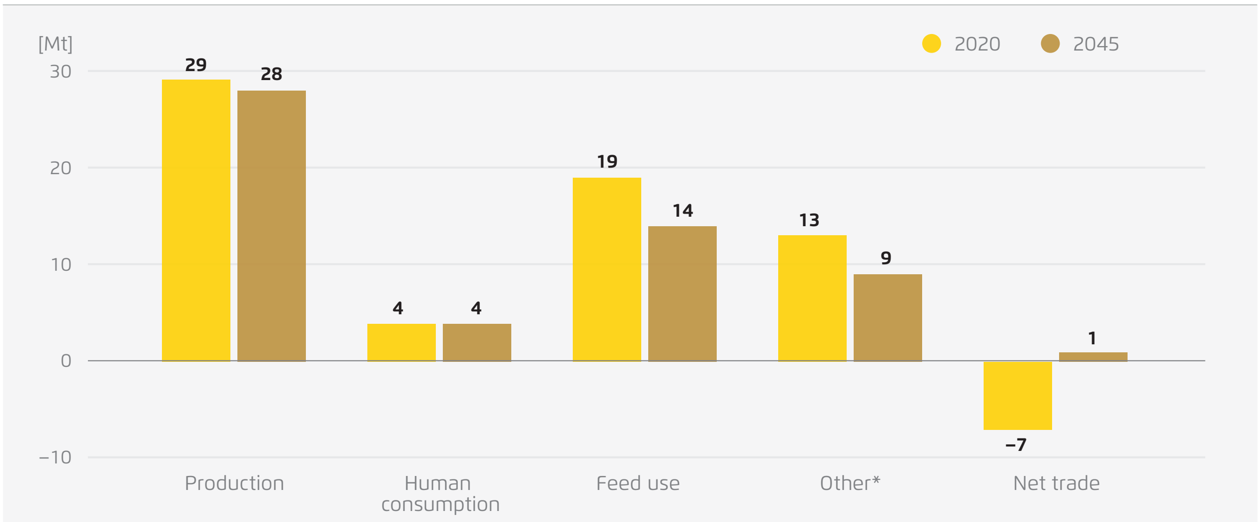
→ Fig. 32



Agora Agriculture based on CAPRI results. *Other = waste, industrial and other uses

Rapeseed and sunflower – EU market balances in 2020 and 2045

→ Fig. 33



Agora Agriculture based on CAPRI results. *Other = waste, industrial and other uses seem counterintuitive at first (EEA 2024a, Prăvălie et al. 2021, Ray et al. 2012). However, further improvements are to be expected in the fields of agricultural technology, machinery, irrigation and plant breeding (Lipper et al. 2018, Senapati & Semenov 2020). Many farms have great potential for technical and agronomic improvement, which could be unlocked through improved technology, capacity building and knowledge transfer. This will help to further narrow the persistent and regionally wide yield gap in arable crops (Ma et al. 2016, Schulte-Uebbing & de Vries 2021). According to Schils et al. (2018), grain yields in Europe are only at 30–90% of their potential. Moreover, Rezaei et al. (2023) show that crop yields in temperate regions can increase significantly under changing climate conditions if investments are made in improved nutrient management and irrigation.

Driven by falling demand for animal feed, the trade deficit for feed grain, oilseeds and other protein feedstocks is declining. In our scenario, the EU remains a net exporter of cereals. A detailed overview of the trade balances in our scenario can be found in Annex Chapter 6.

4.5.3 Policy options

Below, we outline a policy mix to help unlock the economic and environmental potential of arable farming in the EU.

Arable farming in the EU is facing major environmental, economic and social challenges. To meet these challenges, farmers need a reliable and enabling policy environment with available public funds being spent cost-efficiently. This can be achieved if policies at the EU, national and regional levels are well-aligned.

We focus on five policy measures at the EU level:

A) Strengthen innovation partnerships to tap yield potentials and adapt arable farming to climate change
B) Set targets for biodiversity and develop a standalone biodiversity index for agriculture
C) Introduce market-based incentives for the targeted use of plant protection products and fertilisers
D) Incentivise agri-environmental coordination at cross-farm and landscape level
E) Build a European Common Agricultural Data Space

Although not exhaustive, we consider these policy proposals to be key for a sustainable future of EU arable farming. EU policies for an expansion of fruit and vegetable production and the sustainable production of biogas in the EU are not discussed here. The future development of these sectors depends largely on technological progress and energy policies and requires further in-depth analysis, which is beyond the scope of this study.

A) Strengthen innovation partnerships to tap yield potentials and adapt EU arable farming to climate change

The land use efficiency of arable farming in the EU can be improved substantially by producing more plant-based food and less feed for livestock farming in combination with human demand changing accordingly (Chapters 4.3 and 4.4). Another lever is to close yield gaps without putting additional pressure on ecosystems (Rockström et al. 2017). Depending on the production system, the yield gap is large in many EU regions (Ma et al. 2016, Schils et al. 2018, Schulte-Uebbing & de Vries 2021). Climate change and the associated increase in extreme weather events could further widen yield gaps (EEA 2024a). These risks cannot be eliminated, but they can be mitigated and spread.

To tap yield potentials and meet the challenges of climate change, stimuli for investment, innovation and training in EU arable farming are key. With rising prices for fossil fuels, fertilisers, plant protection and freshwater, precision farming and smart irrigation systems are becoming an increasingly important competitive factor. For many EU farms, these technologies are not affordable. Financing is particularly challenging for small farmers and start-ups (European Commission & EIB 2023, CEJA 2023, Barnes et al. 2019).

Co-financed by the European Agricultural Fund for Rural Development (EAFRD), member states grant subsidies for investments in modern farm technology, for cooperation, knowledge transfer and technical assistance. However, according to the European Commission's result indicators dashboard for the CAP 2023–2027, only a small proportion of EU farmers are addressed by these programmes (European Commission 2024l).

Investment subsidies for the purchase of modern equipment for individual farms cannot fill the structural investment gap in EU arable farming. Investments in innovative technologies and cultivation systems realise their full potential only when farmers, agricultural contractors, manufacturers, scientists and consultants cooperate and learn from each other. Tying investment subsidies to participation in projects with a multi-actor approach can therefore improve the outcome of investment activities (Détang-Dessendre et al. 2018). Projects within the EAFRD-funded Agricultural Knowledge and Innovation Systems (AKIS) and the European Innovation Partnerships for Agricultural Productivity and Sustainability (EIP-AGRI) (European Commission 2024g) pursue this cooperative approach. Strengthening such multi-actor networks in the CAP is important to support innovation in EU agriculture. The reduction in EU co-financing for AKIS and EIP-AGRI as part of the last CAP reform therefore went in the wrong direction (Röder et al. 2024). For multi-actor partnerships to have a broad impact on agricultural practice, the transaction costs for participating farmers and cooperation partners need to be reduced.

Beyond investments in technology, knowledge transfer and training on farms, EU policies can also support innovations of societal interest along the entire value chain. Examples include developing a legal framework for sustainability labelling (Chapter 4.3), relaxing the rules for naming plant-based products (Chapter 4.3) and the use of waste and by-products of the food industry in animal feed (Chapter 4.4). Another example is the improvement of the legal framework for new genomic techniques in plant breeding. These techniques can increase the speed of, for example, adaptation to climate change (Langridge et al. 2021) and tolerance to pests and diseases, reducing the need for plant protection (Komal et al. 2023). After controversial debate, the European Commission's proposal for a new regulation on plants produced by certain new genomic techniques could not be adopted in the last legislative period (European Commission 2023i). To reach an early agreement, it is now important to find a robust legal solution to minimise the risk of increasing market concentration in the plant-breeding sector associated with the regulation of property rights in the EU for material generated through new genomic techniques (Kim et al. 2023).

Much of the literature and research on the yield gap and climate adaptation emphasises technological solutions. Snyder et al. (2017) point out that this narrow focus ignores the wider social, economic and political context that shapes farmers' decision-making. Comparative studies on the economic performance of agriculture in Europe underline the importance of socio-economic framework conditions, such as the age of farmers or the level of professional training (Giannakis & Bruggeman 2015). Comprehensive policies for the development of rural areas in the EU are therefore important for strengthening EU agriculture (Chapter 5.5).

B) Set targets for biodiversity and develop a standalone biodiversity index for agriculture

In the EU, arable farming has a major influence on the development of biodiversity. Reconciling biodiversity conservation with the growing demand for agricultural products is a challenge. Therefore, agri-environmental funds for biodiversity must be focused on the most land-efficient measures.

The prerequisite for ambitious biodiversity management in arable farming are clear targets and robust indicators to measure progress. At present, these two conditions are not sufficiently met. This is due to the fact that biodiversity is complex per se (Soto-Navarro et al. 2021, García-Vega et al. 2024). The local need for action to achieve a specific conservation target is context-dependent (Klaus et al. 2023, Oppermann et al. 2020). Focusing on simplified metrics thus carries the risk of missing many types of biodiversity and species (Pollock et al. 2020). However, it is worth seeking workable solutions and reducing complexity as much as possible to mobilise political action.

Current biodiversity policy is informed mostly by a variety of one-dimensional indicators that cover specific facets of biodiversity (Soto-Navarro et al. 2021). We argue that it is possible to integrate the most important of these indicators to develop and implement a practicable standalone biodiversity index for agriculture.

This standalone biodiversity index would:

- Focus on the links between habitat heterogeneity and biodiversity in agricultural landscapes (Section C),
- Be metrically scaled so that incremental progress can be measured and rewarded,
- Be easy and transparent to calculate,
- Be flexible to reflect regional circumstances without jeopardising cross-regional comparability,
- Be able to handle different data qualities,
- Be monitored in high temporal and spatial resolution and at low cost. Remote sensing is particularly suitable for this.

Our proposal for a standalone biodiversity index differs from concepts for multidimensional biodiversity indicators, which are intended to cover not only all dimensions of biodiversity, but sometimes also economic and social implications (e.g., Soto-Navarro et al. 2021, Pollock et al. 2020, ETH Zürich 2024). A valuable inspiration for our concept of a standalone biodiversity index is the guidelines for the development of an OECD farmland habitat diversity indicator (Bayr et al. 2023). These guidelines meet many of the criteria mentioned above. Particularly convincing is the OECD proposal for a three-tiered methodology, similar to the IPCC guidelines for climate reporting. This is very important as the capacities to monitor biodiversity vary across EU member states and regions.

In view of the scientific evidence on the drivers of biodiversity in agricultural landscapes, an index focusing on landscape heterogeneity provides effective information for biodiverse arable farming. Whether in fact one standalone index which focuses on landscape heterogeneity is sufficient or needs to be flanked by key result indicators requires further critical examination (see e.g., Pe'er et al. 2020, Paracchini et al. 2020).

The Nature Restoration Law (NRL) (Regulation (EU) 2024/1991), which was finally approved by EU legislators in June 2024, will shape the efforts of the EU member states for biodiversity improvement in the coming years (Chapter 3.2). During legislative negotiations on the Nature Restoration Law, the requirements for restoring agricultural ecosystems were reduced in scope and stringency (Hering et al. 2023). Achieving an increase in the share of agricultural land with high-diversity landscape features is one of the desired achievements under the Nature Restoration Law. According to Article 14 (7), member states may develop own methodologies to complement the methodology referred to in Annex IV to monitor high-diversity landscape features on agricultural land. This option should be used proactively to widen the perspective to the landscape level and include both configurational and compositional landscape heterogeneity (Section C). A standalone biodiversity index may be a powerful tool for this purpose. Once developed and applied, learnings from the standalone biodiversity index could inform a revision of the legislative targets to align those targets more closely with the indicators used in the index.

C) Introduce market-based incentives for the targeted use of plant protection products and fertilisers

The introduction of levies or tradeable certificates[59] for environmentally harmful inputs or emissions sets price signals that encourage the uptake of environmentally friendly farming practices and technologies. In contrast to command-and-control policies, market-based incentives allow farmers to constantly reassess how they respond to these price signals. Effective pricing of agricultural greenhouse gas emissions (Chapter 5.1), nutrient-balance surpluses

59 We use the term "certificates" to refer to a variety of tradeable policy instruments. In the specific context of a greenhouse gas emissions trading system we refer to "allowances".

and high-risk plant protection products contributes to emissions from agriculture being reduced at the lowest economic cost. That being said, market-based instruments cannot fully replace regulatory law but must be embedded coherently in the regulatory framework. This applies to the authorisation of environmentally hazardous inputs, as well as to the protection of particularly sensitive habitats and ecosystems. A triad of coordinated regulatory provisions, market-oriented incentives, and support and information schemes is ideal (Möhring et al. 2020).

Both taxes and tradeable certificates aim at internalising the externalities of private and business activities. In the context of agricultural production, they directly influence the economic excellence of agricultural production systems and provide incentives for alternative production strategies.

In the case of nitrogen management, it makes sense to put a price on the nitrogen surpluses at the farm level, rather than increasing the price of fertiliser itself (Andersen & Bonnis 2021, Johne et al. 2023). Only the share of nitrogen input that is not taken up by the crop and removed with the harvest is environmentally relevant. Excess nitrogen is emitted as ammonia into the air, nitrous oxide into the atmosphere or nitrate into the groundwater.

In the case of plant protection products, in contrast, it makes sense to increase the price of the products themselves. In doing so, it is essential to take into account the toxicological risk profile of the active ingredients, the concentration of the active ingredients in the product and the product-specific permitted application rate (Kudsk et al. 2018, Reus et al. 2002).

The specific design of taxes or levies and tradeable certificates is crucial to their effectiveness and cost-efficiency. The following questions are decisive for the performance of such instruments:

- Who in the value chain will pay the tax or hold the certificates: the farmer, upstream or downstream actors?
- What is the tax base and equivalence rule for certificates?
- How high must a tax be set to achieve a reduction target? How many certificates will be issued and in what time frame?
- How is the initial allocation of pollution rights regulated? Should certificates be grandfathered, benchmarked or auctioned? Are there any exemptions or deductions from tax liability?
- How can government revenues from taxation or from auctioning certificates be returned to the sector so that the international competitiveness of domestic producers is not impaired?

Both levies and tradeable certificates can be introduced either at EU or member state level. In principle, the EU has the necessary competences to introduce both EU levies and certificates. In practice, however, EU taxes can be introduced only by a unanimous decision of the member states in the Council. This increases the risk of opportunistic and dysfunctional instrument design in order to buy political agreement from the member states. The EU has more leeway to introduce certificate schemes, particularly since an Emissions Trading System with allowances for greenhouse gas emissions (EU-ETS) is already in place.

With regard to EU policies for the reduction of nitrogen surpluses and the risk of using plant protection products, these considerations lead to different conclusions. To price nitrous oxide emissions from agricultural soils, it makes sense to integrate nitrogen surpluses into an ETS for agriculture (Chapter 5.1). To reduce the risk of plant protection products, some member states have already introduced national tax models – with varying degrees of ambition and success (Böcker & Finger 2016). This experience at the national level is useful to build upon. The dissemination of best practices among member states can be promoted by the EU setting ambitious and binding targets for reducing the risk from plant protection products and guidelines for equivalency rules. In view of the diversity in the implementation of current instruments as well as public and farm-level administrative capacities, it seems adequate that member states should decide which specific instrument and instrument design they use to achieve the targets set at the EU level.

D) Incentivise agri-environmental coordination at cross-farm and landscape level

Schemes tailored to regional circumstances can often be improved by incentivising cross-farm planning and implementation of agri-environmental measures which require spatial coordination across farm boundaries (Figure 34) (Kleijn et al. 2004, Tscharntke et al. 2012, Westerink et al. 2017). This applies to some of the key building blocks of environmentally friendly agriculture: habitat networking, water protection and the rewetting of drained peatlands (Chapter 4.6).

Practical examples of coordinating agri-environmental measures across farms and stakeholders can already be found today. One example are the cooperations between farmers and water authorities to improve water quality (Amblard 2019, Barataud et al. 2014). Another example are virtual mixed-farming systems, where individual farms integrate their specialised livestock and crop production with other farms to diversify crop rotations and improve nutrient management, thereby increasing resource efficiency and farm resilience (Regan et al. 2017).

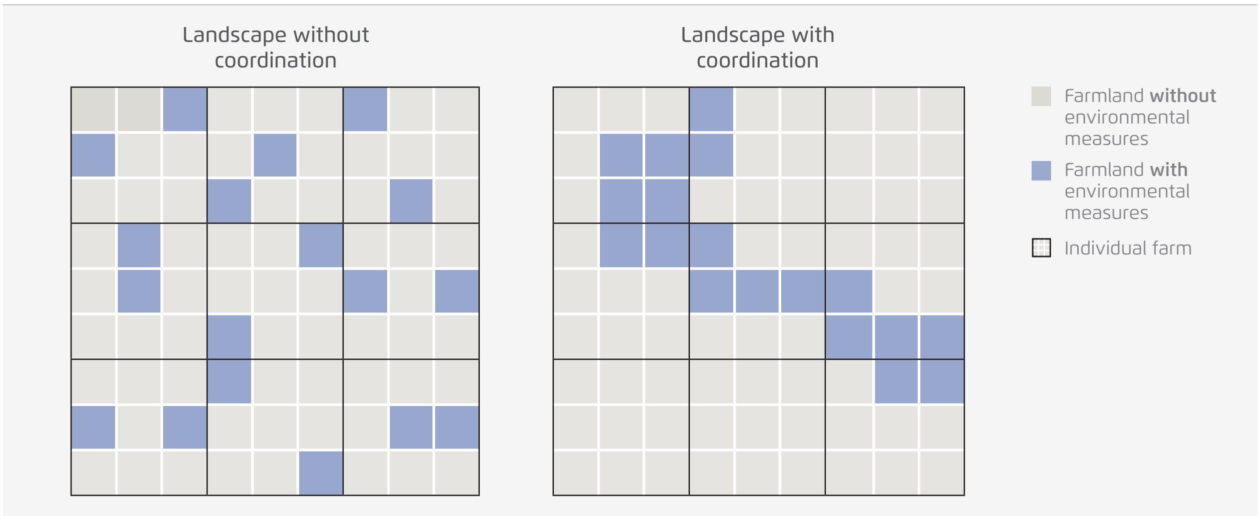
For a widespread implementation, governance systems for spatial coordination will have to take different forms, as regions differ in their political systems, stakeholder networks and agri-environmental conditions (Nguyen et al. 2022, Westerink et al. 2017). Therefore, the following two implementation examples should be considered as sources for inspiration that need careful adaptation to the local circumstances:

- Collaboration through collective action models, such as the Dutch cooperatives.
- Payment of top-ups to individual farms for implementing measures that contribute to landscape targets.

Collective action models are well suited as governance systems for spatial coordination in agricultural landscapes. They have potential to provide geographical and ecological scale benefits and to decrease cost while increasing local stakeholder's capacities and abilities to tackle local issues effectively (Goldman et al. 2007, OECD 2013).

Multi-stakeholder models are already eligible for funding from the current CAP, as member states have the option to make payments to groups of farmers and other land managers (Regulation (EU) 2021/2115). Some member states make use of this option by funding collective action of farmers and other stakeholders,

Cross-farm coordination of environmental measures in an agricultural landscape → Fig. 34



Agora Agriculture

including to cover the overhead costs for coordinating bodies. In the Netherlands, for example, agri-environmental measures in the second pillar of the CAP have been coordinated by regional cooperatives since 2016 (BoerenNatuur 2023). Van Dijk et al. (2015) observe a higher acceptance of agri-environmental measures among participating land users because of closer exchange with each other and the coordinating body. Sanction risk and bureaucracy are reduced because funding applications are collectively administered by the 40 cooperatives.

Multi-stakeholder cooperation is particularly effective when agriculture, nature conservation and administration interact on an equal footing to develop common goals for their region and agree on measures. Professional, neutral process-facilitators who take on coordination and administrative tasks are important for the success of cooperative initiatives. To ensure that individual actors and interests do not dominate multi-stakeholder cooperations, the development of EU standards and codes of conduct could be useful. In addition, it may prove effective to entrust the coordination of cross-farm agri-environmental cooperation to whoever presents the most convincing concept.

Top-up payments to individual farms for measures that contribute to landscape goals can increase the coordination and connectivity of implementation areas in a landscape (Goldman et al. 2007, Nguyen et al. 2022, WBAE 2019). Some options for the design of such a payment scheme are:

- **Agglomeration bonus payments.** Farmers are paid a bonus on top of the fixed payment if the measure area is connected to another relevant area.
- **Threshold or collective bonus payments.** Farmers are paid a bonus on top of the fixed payment if a certain participation level or connected area threshold is reached in a landscape.
- **Threshold payments.** Farmers receive payment for a measure only if a certain level of participation or area covered by measure is reached in a landscape. This bears the risk of no implementation at all if the threshold is not met.

The CAP already offers scope for action to finance the coordination of agri-environmental measures at cross-farm and landscape levels. The institutional incentives to use these degrees of freedom could however be strengthened (Goldman et al. 2007, Pe'er et al. 2020). For example, higher EU co-financing rates could be allocated to cross-farm and spatial coordination and their overhead costs (Chapter 5.2).

An important prerequisite for the effectiveness of cooperative agri-environmental planning is the delineation of functional spatial units. Although the reference to the agricultural landscape level is common in the scientific literature, there are surprisingly few initiatives to operationalise the concept (Andersen 2017). There is an urgent need for research and development here so that spatial units for cross-farm agri-environmental planning can be communicated that both fulfil scientific criteria and are politically manageable.

E) Build a European Common Agricultural Data Space

Digital innovations can support policymakers, administrators and farmers in their decision-making. To exploit their potential, siloed tools need to be linked. A Common Agricultural Data Space in the EU can serve as an effective interface for data processing and exchange (Kosior 2021). Such a data space can be a key lever to unlock the great potential of digital innovations and tools for more sustainable agriculture (Kalmar et al. 2022, Šestak & Copot 2023).

In EU arable farming, the promised technological revolution of digital solutions is still a long time coming (Garske et al. 2021). The reasons and barriers are manifold: high investment costs with uncertain returns, poor functionality and interoperability, corporate lock-ins, lack of training, stakeholders' mistrust in the data-sharing process and concerns about data ownership and sovereignty, to name but a few (Barnes et al. 2019, Hackfort 2023, Paustian & Theuvsen 2017). Digital tools are not yet sufficiently attractive for the breadth of agricultural practice – the digitalisation of EU agriculture needs political tailwind (Lange et al. 2023, Santarius et al. 2023).

Digital innovations can help farmers make decisions on complex issues by linking agronomic, economic and environmental performance parameters (Finger 2023, Walter et al. 2017; but see Lioutas et al. 2021, Visser et al. 2021). The prerequisite is that a wide range of data from different sources can be processed (Mouratiadou et al. 2023). The potential of a Common Agricultural Data Space can be strengthened by including different actors along the value chain. This applies explicitly to farmers who either lack the financial and human resources to invest in digitalisation or who are not interested in these technologies. It is also important to proactively involve downstream and upstream actors. For achieving that, a Common Agricultural Data Space could be designed as a multifunctional marketplace for goods, services and knowledge transfer.

The political window of opportunity for an ambitious Common Agricultural Data Space is wide open. Within the framework of the EU Strategy for Data, the European Commission has announced the establishment of common data spaces – among others for agriculture (European Commission 2020b). A new EU regulation on harmonised rules on fair access to and use of data (EU Data Act) entered into force on January 2024 (Regulation (EU) 2023/2854). As part of the Digital Europe Programme (DIGITAL), the Agri-DataSpace project started work in October 2022 to pave the way for a European Data Space for Agriculture (AgriDataSpace 2024). This project can draw on many private and public initiatives for improved data sharing along agri-supply chains.

A Common Agricultural Data Space will only contribute to achieving agricultural sustainability challenges if the economic benefits for participating farmers are clear. If farm data is used commercially by third parties, farmers must receive a share of the profits. It must be technically impossible for public agencies to misuse farm data for monitoring and sanctioning purposes.

A clear separation of functional platform domains and a transparent, reliable regulation of data access for platform users are key. This applies in particular to access to non-compulsory farm data. Farmers must be able to see at any time for what purposes what users have access to what data based on what authorisation and condition. On the other hand, farmers can, if they wish, share and sell data for further purposes. This applies to both business-to-business and business-to-government data sharing (Bartels et al. 2020, Kalmar et al. 2022). Data stewards have a special role to play as neutral governors of data exchange. The detailed recommendations by Bartels et al. (2020) and Kalmar et al. (2022) may provide guidance for a functional architecture of Common Agricultural Data Spaces.

Ensuring data interoperability and sovereignty alone will not be sufficient to achieve the desired broad impact of a Common Agricultural Data Space. Linking the administration of CAP payments to the Common Agricultural Data Space would expand its uses. Farmers applying for CAP funds could upload the information from their application to the corresponding Common Agricultural Data Space domain. Both private and public actors can then make offers to farmers for farm data provision. If the Common Agricultural Data Space addresses and integrates all farmers who are eligible for CAP support, this could create a strong pull effect. It may also encourage large private-market players to align their data platforms and tools with the Common Agricultural Data Space standards. The proposal for a Soil Monitoring Law (2023/0232(COD) and the Nature Restoration Law (Regulation (EU) 2024/1991) are accompanied by far-reaching monitoring requirements for member states. A Common Agricultural Data Space can serve to efficiently compile the necessary information, interlink it and make the findings usable for agricultural practice.

Free access to high-resolution environmental datasets and Application Programme Interfaces (API) hosted by public agencies and research institutes further adds to the attractiveness of the Common Agricultural Data Space. These include data on weather and soil, as well as from remote sensing and biodiversity monitoring. This is in line with the EU's commitment to strengthening open data as expressed in the Directive (EU) 2019/1024 on open data and the re-use of public sector information.

4.6 Agricultural peatlands

4.6.1 Scenario

Rewetting most of today's agricultural peatlands in the EU is a key lever to reduce greenhouse gas emissions from the land use sector. Draining organic soils, such as peatlands, for agricultural use results in the oxidation of soil organic matter causing annual greenhouse gas emissions of about 20–40 tonnes of carbon dioxide equivalent (CO_2eq) per hectare (IPCC 2014). Rewetting drained peatlands could to a large extent avoid those emissions (Tanneberger et al. 2021b).

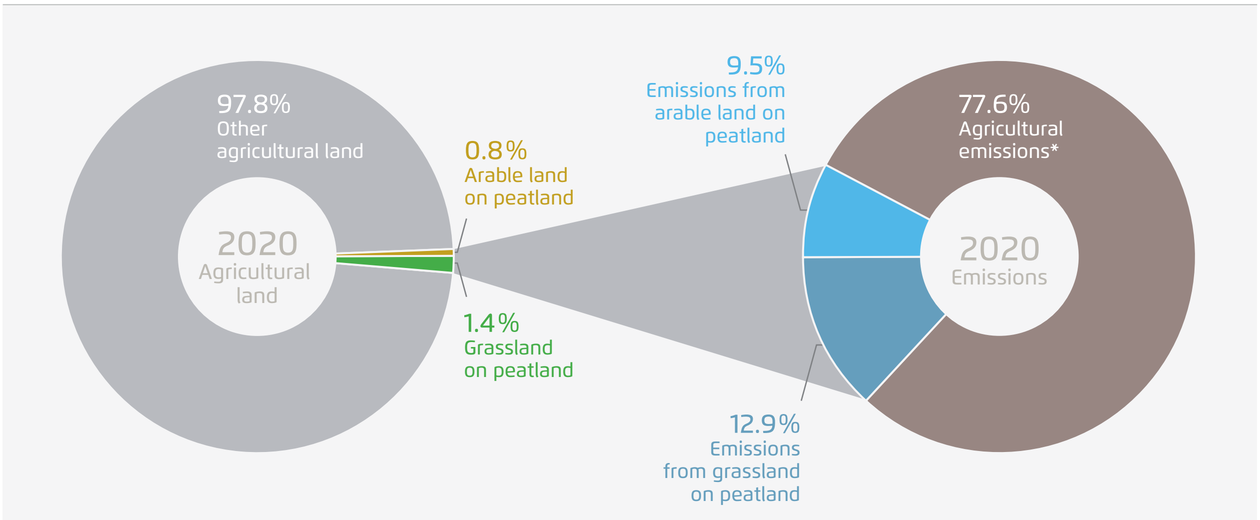
Drained agricultural peatlands account for over 20% of the total greenhouse gas emissions from agriculture and agricultural land use in the EU (Figure 35).[60] About 65% of these emissions come from just three member states: Germany, Poland and the Netherlands, as peatlands are unevenly distributed across member states (Figure 36).

60 These estimates as well as the calculation of emissions reductions throughout this study are based on the National Inventory Reports and the IPCC Wetland Supplement (IPCC 2014), adapted using the calculations of Martin & Couwenberg (2021) (Annex Chapter 7).

We focus on agricultural peatlands because of the prominent role of agricultural use in the total emissions of drained peatlands. Across the EU, drained peatlands under cropland or grassland account for roughly three quarters of total greenhouse gas emissions from drained peatland, while those from forestry contribute roughly one quarter (GMC 2022b). In addition, the potential for emissions reductions per hectare on agricultural peatlands (20–30 tonnes of CO_2eq per hectare per year) are larger than on forested peatlands (6 tonnes of CO_2eq per hectare per year) (Barthelmes 2018). However, emissions from forested peatlands are particularly important for member states with a high proportion of forested peatlands and corresponding high greenhouse gas emissions, such as Finland, Estonia, Ireland, Latvia, Lithuania and Sweden (GMC 2022b).

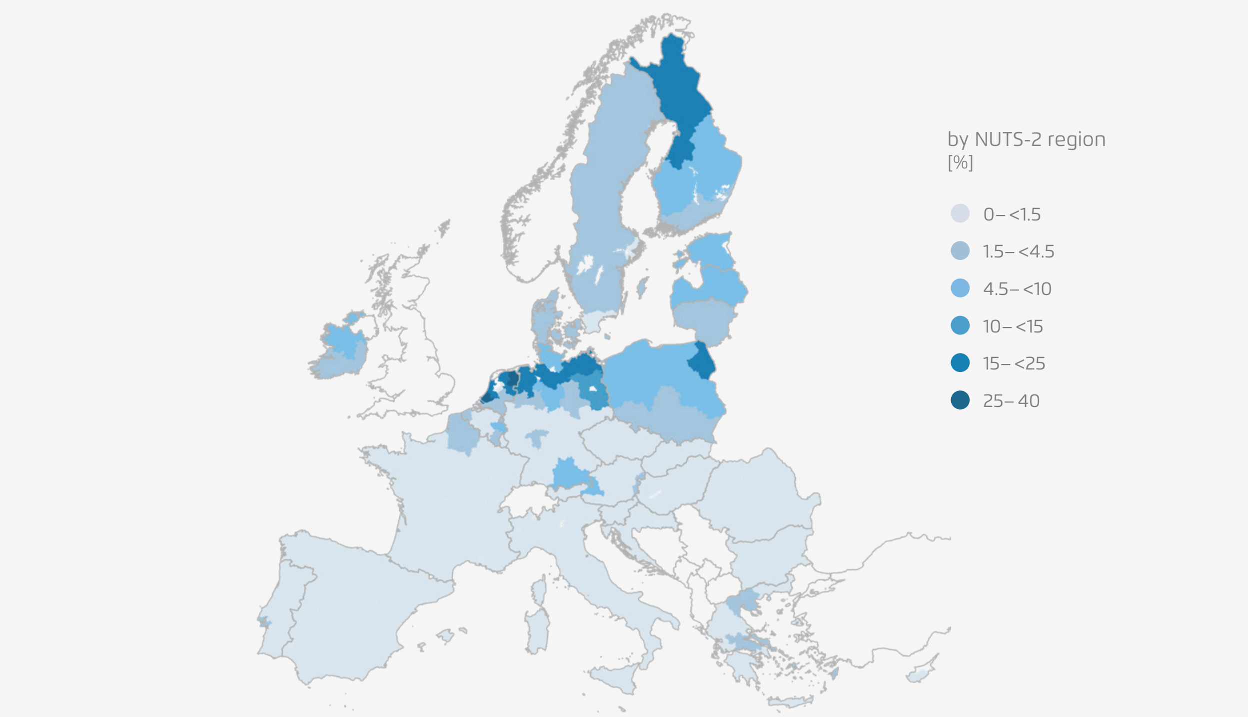
Rewetting peatlands is a widely supported and researched method. In specific cases, alternative measures such as covering peatlands with sand or sediment (if available) while rewetting the body of peat below can also be effective in reducing greenhouse gas emissions from peatlands (Hofer & Pautz GbR & DUENE e. V. 2024). Since the availability of these materials at acceptable cost is spatially limited and there is limited evidence of the effectiveness,

Peatland – land use and greenhouse gas emissions in the EU in 2020 → Fig. 35



Agora Agriculture based on CAPRI results, IPCC (2014), Martin & Couwenberg (2021). * without N_2O-emissions from organic soils

Share of peatland in EU Utilised Agricultural Area (UAA) in 2020 → Fig. 36



Agora Agriculture based on CAPRI results

economic viability and ecological impacts of these alternatives, we focus on rewetting and reduced drainage as climate change mitigation measures.

Rewetting 80% of the EU's currently drained peatlands can achieve a reduction of annual emissions by about 70 million tonnes CO_2 equivalent ($MtCO_2eq$). This is a reduction of almost 70% in total annual peatland emissions. Income opportunities on wet peatlands can arise for farmers, based on new value chains for paludiculture biomass[61] and solar photovoltaics (PV) as well as potential rewetting payments. We show this in the scenario, which includes the following elements:

A) Rewetting 80% of agricultural peatlands (used as follows):
   - 80% paludiculture
   - 20% wet wilderness and solar PV

B) Using 20% of agricultural peatlands as shallow-drained grassland

61 Paludiculture is a peat conserving form of agricultural production and forestry on rewetted peatland (Nordt et al. 2022). In this study we focus on agricultural production such as growing reeds, sedges and cattail.

Both the 80% paludiculture and 20% wet wilderness and solar PV refer to the rewetted 80% of total agricultural peatlands. Their shares in the total agricultural peatlands are 64% and 16%, respectively. Below we present our scenario and describe its environmental and socio-economic impacts. In Chapter 4.6.4 we discuss EU policy options to incentivise and support the changes outlined in the scenario.

A) Rewetting 80% of agricultural peatlands

Rewetting the majority of the EU's agricultural peatlands contributes significantly to emissions reductions in our scenario. Agricultural peatlands in the EU cover 3.5 million hectares and about 2% of the EU agricultural area. In our scenario, 80% of these lands, or 2.8 million hectares, are rewetted, with water tables close to the surface. This prevents both carbon dioxide emissions resulting from low water levels as well as methane emissions from episodic high water levels, and allows wet-adapted plants to establish (Kreyling et al. 2021). Rewetting 80% of the agricultural peatlands would avoid greenhouse gas emissions worth

14 billion euro per year compared to 2020, calculated with an exemplary carbon price of 200 euro per tonne CO_2. This is far above the cost of rewetting, including the opportunity cost resulting from giving up dry agriculture on peatlands (Chapters 4.6.3 and 4.6.4). The current state of the scientific debate shows that it is not only economically efficient, but also technically possible to rewet large areas of peatlands if supported by a suitable political framework (Chapter 4.6.4) (GMC & Wetlands International 2022, Grethe et al. 2021, Isermeyer et al. 2019, Tanneberger et al. 2021a).

We expect the overall level as well the distribution of rewetting within and between member states to depend on several factors such as peatland degradation, water availability, and hydrological cost. It also depends on socio-economic and cultural factors such as the opportunity cost of rewetting and political institutions and processes. As there is a lack of solid data about exactly how much land can be rewetted at what cost, 80% rewetted area is a rough estimate, which we applied to all EU NUTS-2 regions (Annex Chapter 7).

The fully rewetted 2.8 million hectares in our scenario are used in different ways: paludiculture on 80% and solar PV and wilderness areas on 20%.

80% paludiculture on rewetted peatland

Of the rewetted peatland, 80% is used to produce biomass by cultivating diverse paludiculture crops, such as reeds, sedges and cattail. Paludiculture is a production system that allows continued agricultural use and income on wet organic soils. Currently, value chains for paludiculture biomass are still scarce (Ziegler et al. 2021). But paludiculture can be accelerated by a growing demand for biomass needed by other sectors to reach their climate targets (Chapters 4.2 and 4.6.4). The emerging new markets have a high potential for the use of paludiculture biomass, for example for the packaging industry, as insulation material in the construction sector, and as a substitute for peat as a growing medium in horticulture. In addition to this material use, paludiculture biomass can be used as an energy source.

The majority of the EU's agricultural peatlands fall within the temperate climate zone, which has distinct seasons and relatively mild temperatures. For these peatlands, we expect mainly five paludiculture crops to be suitable to serve the growing demand for biomass: sedges, reed canary grass, reeds, cattails and peatmoss (Figure 37).

Examples of paludiculture crops and potential biomass uses → Fig. 37

	Paper	Panels for furniture	Insulation/construction material	Horticultural growing medium	Biogas
Sedges					✓
Reed canary grass	✓	✓	✓		✓
Reed	✓	✓	✓		✓
Cattail	✓	✓	✓		✓
Peatmoss			✓	✓	

Agora Agriculture based on Nordt et al. (2022)

20% wet wilderness and solar PV on rewetted peatland

Of the 2.8 million hectares of rewetted peatland in our scenario, 20% is used for wet wilderness and solar PV, with reduced or no biomass harvesting. Solar PV is an attractive land use option to provide income opportunities on rewetted peatlands. In our scenario, 4% of the rewetted peatland area is used in this way. This is about 12% of the total additional capacity of ground-mounted PV to be installed on agricultural land (Annex Chapter 3). This is a conservative estimate; it could be higher. The overall amount and the distribution of solar PV on rewetted peatland depends among others on the cost of production, progress made for the installation of the modules on wet soil, and the grid-connectivity options.

Some of the rewetted peatlands are likely to have limited infrastructure needed to supply paludiculture biomass to value chains or for energy production. This is particularly the case in areas with limited access to major transport routes, low biomass-production potential or no connection to electricity grids. In such remote areas, wet wilderness could promote biodiversity conservation.

B) Using 20% of agricultural peatlands as shallow-drained grassland

Rewetting may be societally undesirable on some agricultural peatlands for socio-economic, agronomic, or hydrological reasons. For example, the economic cost of providing water for rewetting is substantially higher for some peatlands than for others. This requires alternative land use options with reduced drainage. Reducing drainage does not equate to full rewetting from a climate perspective, because emissions increase with decreasing water levels (Hirschelmann et al. 2020). However, reducing drainage to raise water levels can be an option to reduce emissions from peatlands that are not fully rewetted.

In our scenario, 20% of the agricultural peatlands are used as shallow-drained grassland with an elevated water table. This implies an annual average water table of about 30 centimetres below the soil surface (European Commission 2022c). In our scenario, these areas are used as extensive pasture or other extensive grassland use with adapted management and feeding (Chapter 4.4).

The geographical distribution of shallow drained grasslands depends on local conditions. For an efficient distribution, relevant criteria include the costs of rewetting, the socio-economic implications and the role of cultural heritage (Buschmann et al. 2020, Grethe et al. 2021, Lehtonen et al. 2022).

4.6.2 Environmental and climate impacts

Rewetting peatlands to a saturated state is an effective way to reduce greenhouse gas emissions from peatlands (Balode et al. 2024). In addition to this main environmental benefit, peatland rewetting can help achieve climate neutrality through other functions:

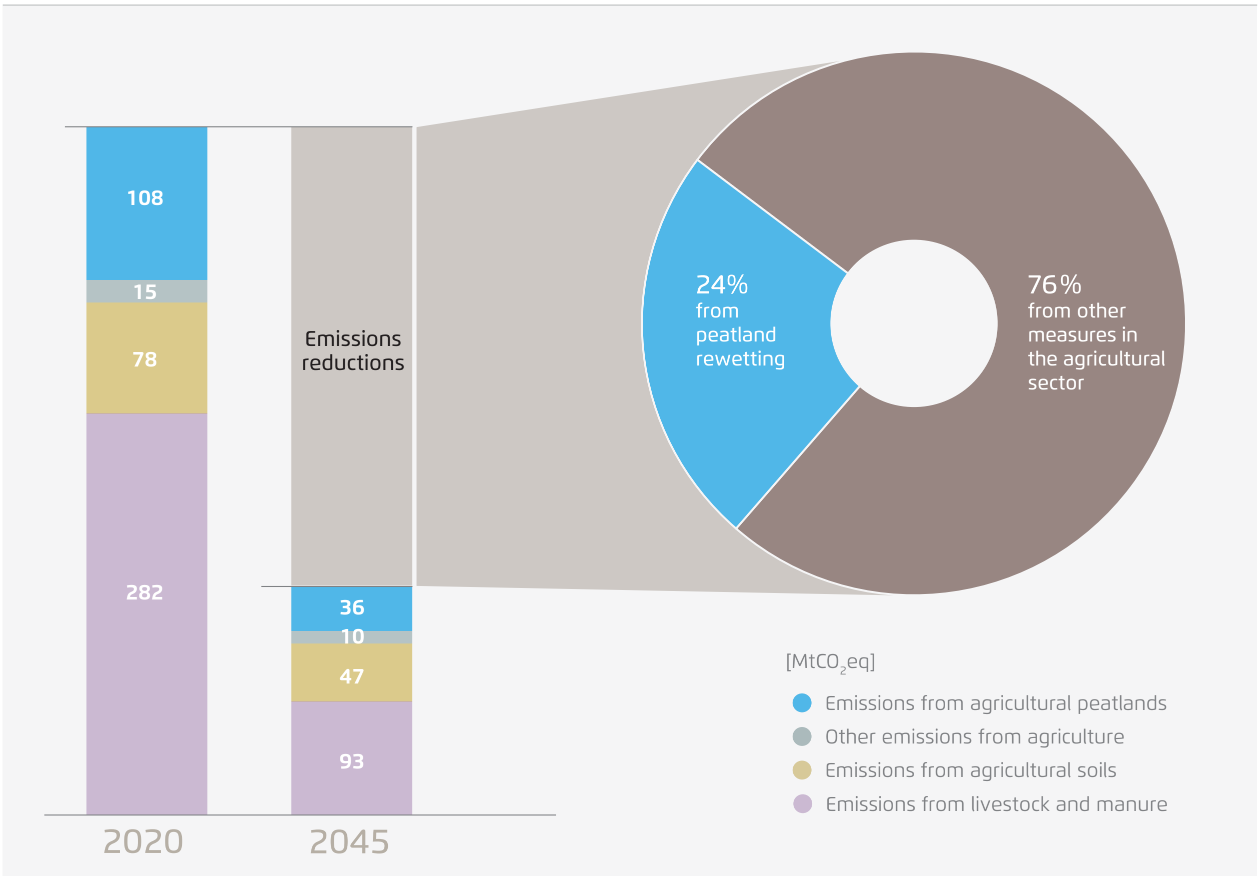
- Rewetted peatlands can act as carbon sinks in the future if they recover their capacity to accumulate carbon after rewetting (Schwieger et al. 2021).
- Paludiculture biomass can contribute to carbon storage in products (Lahtinen et al. 2022). The climate change mitigation effect of this function increases when paludiculture biomass is used to produce long-lived rather than short-lived products.
- Products derived from paludiculture biomass can generate substitution effects by replacing fossil-based products (Ziegler et al. 2021).
- Solar PV on rewetted peatland can replace fossil with renewable energy.

On average in the EU, rewetting one hectare of grassland and one hectare of arable land reduces annual greenhouse gas emissions by up to 20 tonnes of CO_2eq and 30 tonnes of CO_2eq, respectively (Tanneberger et al. 2021b). Rewetting 80% of the EU's agricultural peatlands would thus result in a reduction of annual emissions of about 70 MtCO_2eq. In our scenario, peatland rewetting alone contributes to almost a quarter of the total emissions reductions from agriculture and agricultural peatlands, from only about 2% of the total agricultural land (Figure 35 and Figure 38).

During the process of rewetting peatlands, methane (CH_4) emissions increase and may temporarily be substantial. However, in a net-balance, the increase in CH_4 emissions is outweighed by the reduction of the CO_2 emissions (Günther et al. 2020). With 80% of the EU's agricultural peatlands rewetted and 20% being used as shallow-drained grassland, annual CH_4 emissions are estimated to increase by 13 $MtCO_2eq$ compared to 2020, but the reductions in annual CO_2 and N_2O emissions are much larger: 74 $MtCO_2eq$ and 11 $MtCO_2eq$ respectively, yielding a total reduction of greenhouse gas emissions of 72 $MtCO_2eq$.

Besides its climate change mitigation potential, peatland rewetting can help increase biodiversity and provide water-related ecosystem services such as improved water quality (Kløve et al. 2017). Except for greenhouse gas emissions, we do not assess the impact of our peatland scenario on other sustainability dimensions in depth. In general terms, biodiversity is positively impacted by rewetting, paludiculture and raised water levels. Rewetting can provide habitats for species that are adapted to the specific conditions present in peatlands (Martens et al. 2023, Tanneberger et al. 2022). Shallow-drained grasslands, which cover about 700 000 hectares in our scenario, also play an important role from a biodiversity perspective. They could promote biodiversity by contributing to mosaic structures which ensure biotope connectivity (Grethe et al. 2021).

Peatland – greenhouse gas emissions reductions potential in the EU in 2045 → Fig. 38



Agora Agriculture based on CAPRI results, IPCC (2014), Martin & Couwenberg (2021)

Besides multiple benefits, potential trade-offs should be considered. Some drained peatlands are protected habitats and rewetting and paludiculture use may in certain cases lead to conflicts between rewetting and the conservation of species in drained peatland ecosystems (Tanneberger et al. 2022). The EU Habitats Directive (92/43/EEC), for example, may restrict the rewetting of some protected peatlands if this would have a negative impact on species found on drained peatlands (Hirschelmann et al. 2023). For example, rewetting of extensively used grasslands may be counterproductive for the conservation of sensitive species such as orchids.

Finally, rewetting peatlands positively affects the hydrology in peatland regions (GMC & Wetlands International 2022). It can stop hydrological processes responsible for nutrient leaching from the topsoil layer, restore the buffering function and the regional water-regulation capacity of peatlands, and prevent regional groundwater levels from declining further (Joosten & Clarke 2002, Kløve et al. 2017, Kotowski et al. 2016). Rewetted peatlands also have a positive effect on regional temperature regulation by being cooler in the summer than mineral soils (Joosten & Clarke 2002).

4.6.3 Socio-economic impacts

Large-scale rewetting of peatlands substantially changes existing land use systems that have been the basis of agricultural production for a long time, and which have been drained with the support of wider society to produce food in times of scarcity. Rewetting these areas not only requires a change in people's perception of what "production" is, it also has social and economic implications. As more than half of the potentially rewetted land is grassland, dairy farms are particularly affected (Chapter 4.4). Therefore, socio-economic impacts need to be carefully considered at the EU, national, regional and farm level, even if not always quantifiable.

Tradition, history of use and cultural aspects can strongly influence the implementation of rewetting and must be accounted for (Buschmann et al. 2020). Broad and long-term stakeholder processes can address these aspects and improve the outcome for society as a whole by facilitating dialogue on equal terms and making use of local and practical knowledge (Grethe et al. 2021, Wittmayer et al. 2022).

Rewetting drained peatlands involves costs in different dimensions, including investment costs to change the hydrology, maintenance costs to keep peatlands wet and opportunity costs of rewetting.

Rewetting peatlands requires changes to the water infrastructure. These hydrological costs of rewetting include construction and planning costs which have been assessed for only a few rewetting projects in the EU and vary greatly (Mathias 2022, Wichmann et al. 2022a). The range of costs is due to differences in management, peatland type, degree of degradation and other socio-economic and environmental variables. The European Commission (2022c) proposes to include the following cost categories and indicates cost ranges where available:

- Average investment costs for rewetting range from 955 to 4 735 euro per hectare,
- Maintenance costs range from 29 to 470 euro per hectare per year,
- Transaction costs (for example coordination and communication).

For our scenario, that would sum to estimated investment costs of about 3 to 13 billion euro until mid-century, and annual maintenance costs of up to about 1 billion euro per year in 2045. Further hydrological cost categories for rewetting projects may include research and analysis, authorisation procedures and coordination and communication (Wichmann et al. 2022a).

The change in land use due to rewetting leads to the end of current agricultural production systems on peatlands which causes opportunity cost. The opportunity cost of rewetting is estimated by the European Commission (2022c) at an average of 525 euro per hectare per year in the EU. The level of opportunity costs varies among regions and depends on the economic profitability of current production systems and, according to our own calculations, could be higher in general (Chapter 4.6.4). Over time, it can decrease, depending, for example, on the development of alternative income sources, such as paludiculture biomass and solar PV.

To reduce the opportunity cost of rewetting and for peatlands to remain an attractive and viable resource for farmers, the development of new income opportunities based on rewetted peatlands is essential. Both paludiculture and solar PV have the potential to become long-term and economically viable land use options on rewetted peatlands. While it is not production in the traditional sense, selling mitigated emissions, or in the long-term carbon removals, from rewetting is another potential source of income for farmers (Wichmann et al. 2022b). How this could work in an EU climate policy framework is discussed in the policy options (Chapter 4.6.4).

Paludiculture crops on peatlands can be a basis for new biomass markets and an alternative to emissions-intensive products (Lahtinen et al. 2022, Nordt et al. 2022). In our scenario, rewetted peatlands have an annual biomass-supply potential between about 8 to over 18 million tonnes of dry matter in 2045. This is based on 2.2 million hectares of peatland dedicated to biomass production, multiplied by an unweighted average annual yield potential of between 3.5 to 8.2 tonnes of dry matter per hectare for the most common paludiculture crops in temperate zones (Dahms et al. 2017, Närmann et al. 2021, Nordt et al. 2022) (Annex Chapter 3).

Potential markets for this more sustainable source of biomass are the construction sector, bio-refineries, horticulture and bioenergy production (Temmink et al. 2023). The decarbonisation strategies in these sectors will drive demand for low- and zero-emissions biomass. As a first approximation, the potential EU market for paludiculture peatmoss as a growing medium for plants was estimated to be worth up to 2 billion euro per year (ZukunftMoor GmbH 2024).

For farmers to be part of the development of new markets for paludiculture biomass, there are initial investment costs for establishing paludiculture and acquiring specialised technology. A study from Wichmann et al. (2022a) shows paludiculture-establishment costs from pilot projects and expert estimates in Germany to average 10 000 euro per hectare with a range from 2 000 to 128 000 euro per hectare. This does not include investments in wet-adapted equipment for harvesting and transportation. According to Wichmann et al. (2022a), the level of investment costs depends on regional factors, the intended use and crop, the size of the area, the cost of planning, authorisation and technical implementation, and the potential impact on settlements and infrastructure. Data to quantify these costs are still scarce, as there have been no large-scale paludiculture projects to date.

Solar PV on rewetted peatlands is another promising sustainable land use option. In our scenario, the installation of solar PV on peatlands contributes about 73 gigawatts, or 7% of the installed capacity, to the EU's estimated total installed solar capacity in 2045 (Chapter 4.1). This is calculated assuming an installation of solar PV modules on 4% of rewetted peatlands and a power rate of 0.75 megawatts per hectare. Knowledge and experience on the installation of solar PV modules on peatlands and related rewetting activities are scarce (KNE 2022). The 0.75 megawatt are therefore a cautious estimate compared to the usual 1 megawatt per hectare for large-scale ground-mounted solar plants.

Even though standard ground-mounted solar PV is more efficient from a profitability and energy perspective, peatland solar PV can provide an alternative income opportunity for farmers and thus act as a pull factor for rewetting. At the same time, it is important to better understand and avoid potential negative impacts of installing solar PV on rewetted peatlands, for example on peat conservation, water balance or biodiversity (GMC 2022a, KNE 2022).

4.6.4 Policy options

The process of rewetting peatlands is challenging because it will fundamentally change current land use options and the appearance of certain rural landscapes. This will affect the local population, many of whose families have lived and worked in peatland-rich regions for generations. It is therefore essential to organise a rewetting process with long-term political commitment that provides planning security and the development of new production and income opportunities. Stakeholder dialogues accompanying peatland policy making are important to understand and balance different perspectives and to make use of local and regional knowledge, creativity and entrepreneurship.

In this chapter, we describe policies at the EU level that can support a more sustainable and economically viable peatland use in the EU. We focus on two policy areas:

A) Include emissions from peatland in climate policy
B) Support the development of markets for paludiculture products

The inclusion of emissions from agricultural peatlands in the EU climate policy framework with climate change mitigation targets and financial incentives could stimulate the rewetting process and support farmers and processors until paludiculture products offer economic perspectives in the long term.

Next to EU-level peatland policies, national and regional policies and strategies are decisive. For example, policies are needed to facilitate and incentivise coordination among landowners to enable rewetting entire peat bodies, as peatlands stretch across farm boundaries. Such coordination can also be incentivised by EU policies (Chapter 4.5.3).

National and regional policies could, and in some member states[62] already do, entail regional targets and long-term objectives for peatland rewetting. Depending on the regional circumstances, this could be combined with long-term investments, funding, the creation of institutions responsible for coordinating the rewetting of peatlands, and an adaptation of the legal framework to establish a reliable pathway for farmers and other stakeholders in peatland-rich regions. The regional level is also key to identifying the most appropriate measures for each peatland region to best meet environmental objectives (climate, biodiversity, water retention and quality) and optimise production opportunities (paludiculture, solar PV).

Some EU policies already in place today play a role in providing incentives for national and regional action on peatland. These include the EU Water Framework Directive (2000/60/EC), the EU Biodiversity Strategy (European Commission 2021f) and the objectives formulated under the Nature Restoration Law (NRL) (Regulation (EU) 2024/1991). The Nature Restoration Law sets rewetting targets specifically for agricultural peatlands. With 7.5% of peatlands rewetted by 2030, about 13% by 2040 and about 17% by 2050, these targets are unambitious compared to what is considered feasible in the scientific debate (GMC & Wetlands International 2022, Grethe et al. 2021). Not only are the existing rewetting targets low, the instruments to achieve them are almost entirely missing and most of those that do exist are inadequate (Chen et al. 2023). Setting ambitious rewetting targets and implementing effective policy instruments will be important if incentives to reduce emissions from agricultural peatlands are not, or are not sufficiently, provided by EU climate policy.

A) Include emissions from peatland in climate policy

For farmers to rewet currently dry peatlands, a reliable policy pathway with clear targets and financial incentives is needed. Funding is especially necessary during a transition period until profitable wet value chains are developed. Farmers' and landowners' willingness to rewet is linked to socio-economic aspects such as cooperation among local stakeholders and financial compensation (Schaller et al. 2011). Given the achievements of those who drained the land in the past and contributed to food security and regional economic development, enforcing rewetting predominantly through regulatory law with farmers having to carry the financial burden would be perceived as unfair.

62 National strategies exist especially in those member states with a high share of greenhouse gas emissions from drained peatlands, including Austria, Denmark, Finland, Germany, Ireland and Lithuania with differently ambitious targets (UNEP 2022).

EU climate policies can support greenhouse gas emissions reductions from agricultural peatlands in several ways, such as:

- Having a combined emissions mitigation target for agricultural peatlands and agriculture and including emissions from agricultural peatlands in carbon pricing.
- Funding reliable rewetting payments and aligning Common Agricultural Policy (CAP) payments to support the wet use of peatlands.
- Supporting the scaling-up of voluntary carbon market schemes including peatlands.

EU climate policy can also help to create value chains for paludiculture biomass by incentivising the use of renewable feedstocks such as paludiculture to replace fossil feedstocks (for more on this, see Section B).

Having a combined emissions mitigation target for agricultural peatlands and agriculture and including emissions from agricultural peatlands in carbon pricing

A combined mitigation target that includes emissions from agricultural peatlands and agriculture would make the link to agricultural activities more visible (Chapter 5.1). From a purely technical perspective, it does not matter under which sectoral target peatland emissions fall, as long as sectoral targets are equally ambitious. In practice however, attributing emissions to sectors with a sectoral identity that are subject to a given set of policies contributes to clarifying responsibilities and ownership in general (such as "agriculture", consisting of "farming enterprises" and being subject to "agricultural policies").

Carbon dioxide and methane emissions from the EU's drained agricultural peatlands are currently reported under the Land Use, Land-Use Change and Forestry (LULUCF) category and are governed by the LULUCF Regulation ((EU) 2018/841). The emissions from agriculture, in turn, are covered by the Effort Sharing Regulation ((EU) 2018/842). Emissions from agricultural peatlands are thus governed separately from emissions from agriculture in the climate framework, even though agricultural peatlands are an integral part of the agricultural holding and farm management decisions. The LULUCF regulation recognises wetland restoration as an effective instrument for achieving environmental targets more generally; however, peatland-specific emissions reductions targets do not exist at the EU level.

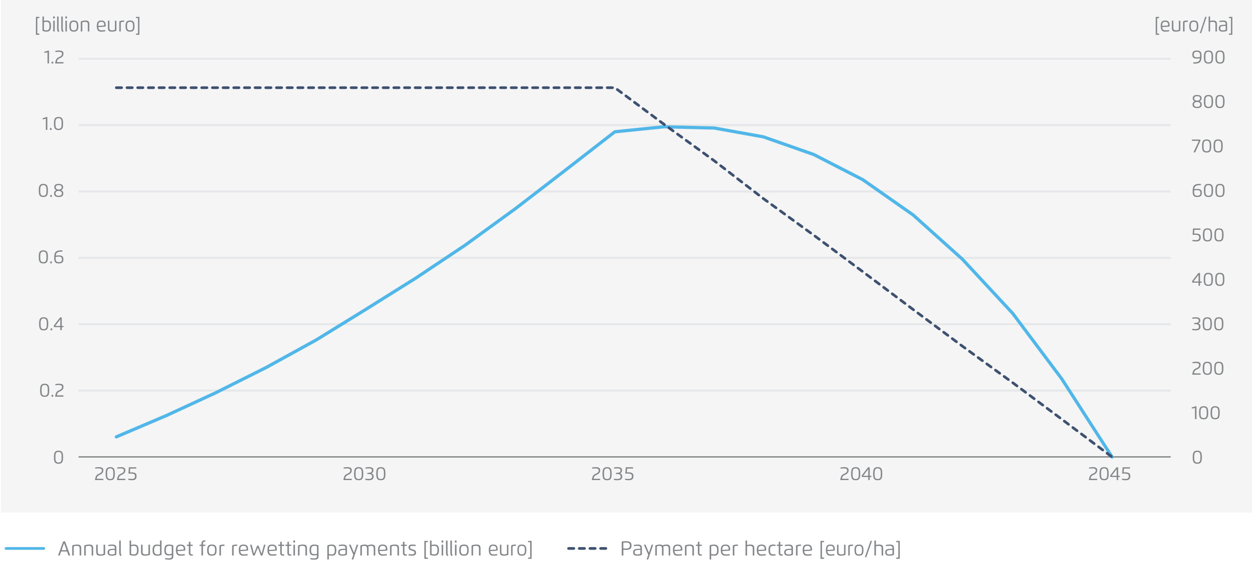
Carbon pricing and the integration of emissions from drained peatlands into a potential EU Emissions Trading System (ETS) for agriculture and agricultural peatlands would incentivise rewetting and provide long-term predictability with legally binding emissions reductions (Isermeyer et al. 2019) (Chapter 5.1).

One implementation option for emissions from agricultural peatlands would be to annually allocate carbon allowances to peatland farmers at no cost ("grandfathering") at the level of current emissions in a first phase of the implementation period (Trinomics B.V. 2023). Farmers who chose to rewet would then have the possibility to sell or lease the allowances to other market participants, dependent on the design of the ETS. This would function similarly to public payments for rewetting (see below). At the beginning, such an economic incentive is needed to cover the different costs of rewetting (Chapter 4.6.3). The share of freely distributed allowances may be phased out over a predetermined period depending on the availability of alternative value chains. Due to the likely irreversibility of rewetting, governments may need to secure financial support through additional public payments in case the price falls below a certain threshold (Isermeyer et al. 2019).

Funding reliable rewetting payments and aligning CAP payments to support the wet use of peatlands

Funding reliable public rewetting payments over a transitional period would be relevant either if emissions from peatlands are not included in an ETS, or if they are included and the carbon price in that ETS falls below a certain threshold. Such funds may be generated from the revenues of auctioned allowances under the EU-ETS, the CAP budget, national and regional budgets, or most likely a combination of those.

Exemplary path for the budgetary costs of peatland rewetting payments in the EU → Fig. 39



Agora Agriculture

To demonstrate the size of the budgetary requirements, we estimate the budget for rewetting payments in case of no inclusion of emissions from peatland in an ETS. For the 2.8 million hectares rewetted peatland in our scenario, the total cost for rewetting payments for the period 2025 to 2045 would be about 12 billion euro (Annex Chapter 7). The maximum annual budget would be about one billion euro in 2036 (Figure 39).

This exemplary estimate is based on several assumptions:

- An EU average short-term annual opportunity cost of 830 euro per hectare as a proxy for a rewetting payment. This is based on weighted land rents for long-term opportunity cost, adjusted according to Domke (2023) for short-term opportunity cost (Annex Chapter 7). This value is higher than the value of 525 euro per hectare estimated by the European Commission (2022c).
- The area rewetted per year increases linearly each year from about 70 000 hectares in 2025 to about 220 000 hectares in 2045.
- The payment is paid fully until 2035 and is then phased out linearly until 2045.

Such a payment design would result in a low budgetary burden in the beginning (due to few hectares being rewetted) and towards the end of the period (due to the gradual phasing out) with a maximum annual burden of about one billion euro in the middle of the implementation period. The design would incentivise farmers to rewet early, as they would benefit relatively more from the payment. From a climate change mitigation perspective, early rewetting would also be beneficial.

We consider the average level of the per-hectare payment for rewetting to be indicative only. It would have to differ strongly among member states and regions according to opportunity costs. In addition, fairness as well as effectiveness considerations may play a role. A rewetting payment based on the medium-term opportunity cost would probably be too low at the beginning of the rewetting period and too high towards the end, for example, due to the development of new income opportunities from wet uses.

A rewetting payment based on the opportunity cost of agricultural land does not cover all expenses of rewetting. Further funding is needed, for example for establishing institutions, managing processes and to support investment, including for hydrological measures, adapted technologies and the establishment of paludiculture. These would likely be covered predominantly by national or regional funds. Public payments may also be needed for some of the 20% shallow drained grasslands.

As climate change mitigation is one of the objectives of the CAP, it can be part of the climate policy funding mix for peatland rewetting. Already today, in some member states, funding for peatland rewetting is part of the second pillar through the European Agricultural Fund for Rural Development (EAFRD). Its current peatland funding schemes include rewetting payments and habitat management in the form of agri-environmental measures. However, to achieve large scale rewetting in the EU, further funding from within or outside the CAP is required and the current CAP has to be aligned to send a clear signal towards peatland rewetting.

In a future public goods-oriented CAP (Chapter 5.2), part of the budget could be used for peatlands to fund different elements of peatland rewetting such as:

- Rewetting payments (such as calculated above),
- Investments, including for hydrological measures, peatland adapted technologies and the establishment of paludiculture (Wichmann 2018),
- Provision of other public goods on wet peatlands, including for biodiversity and water quality (Wichmann 2018).

Apart from directly funding rewetting and other public goods provided by wet peatlands, the CAP is also important in shaping the policy environment to support rather than hinder rewetting. An example of the latter is that wet-farming practices on peatlands were not eligible for CAP funding before the 2023 reform and after the reform uncertainties persist (GMC & Wetlands International 2021, Wichmann et al. 2022a). In order to support peatland rewetting, all wet farming practices on peatlands ought to be eligible for CAP payments (Wichmann et al. 2022a). In a future CAP – when alternative value chains exist and farmers have had the opportunity to rewet and adapt – phasing out payments for dry farming practices on organic soils would further incentivise rewetting.

Another example of how the CAP influences peatland rewetting are the conditionality requirements for the Good Agricultural and Environmental Conditions (GAECs) (Chapter 5.2). On the one hand, GAEC 1 requires farmers to maintain permanent grassland, which means that it may work against the establishment of paludiculture and thus discourage peatland rewetting (Trinomics B.V. 2023). On the other hand, GAEC 2 provides some form of peatland protection (Trinomics B.V. 2023), although the actual level of protection and implementation varies between member states (European Commission 2022g). These examples show that tailoring all aspects of the CAP to remove barriers to rewetting is important.

A possible EU public funding source outside the CAP is the European Regional Development Fund (Regulation (EU) 2021/1058). This is a structural fund that supports investments in rural areas with an environmental focus. It is therefore suitable for funding peatland-related investments complementary to CAP funding, for example for planning, project management and investments in peatland-adapted technologies (Wichmann 2018).

Supporting the scaling up of voluntary carbon market schemes including peatlands

Scaling up voluntary carbon markets can mobilise private funds for rewetting peatlands (Von Unger et al. 2019, Wichmann et al. 2022a). They can function as a supplement to mandatory climate change mitigation pathways, especially in the period when the land use sectors are not yet included in carbon pricing (Chapters 4.2.4, 4.7.4 and 5.1). Voluntary carbon markets are platforms where parties that emit greenhouse gases can voluntarily buy carbon certificates from parties that have reduced or removed emissions. For companies, the voluntary compensation of their greenhouse gas emissions and public communication are important reasons for investing in natural climate protection projects such as peatland rewetting (Sechi et al. 2022). Currently, examples for the integration of peatland emissions into voluntary carbon markets remain few and small-scale across Europe. They include MoorFutures in Germany, Valuta voor Veen in the

Netherlands and the Peatland Code in the United Kingdom (Sechi et al. 2022).

Standardising the quality of monitoring, reporting and verification would increase the credibility of certificates (Greifswald University et al. 2022) and can help make voluntary carbon markets more attractive to businesses. A first step in this direction is the Carbon Removals and Carbon Farming (CRCF) Regulation (2022/0394(COD)) for permanent carbon removals, carbon farming and carbon storage in products that has recently been agreed by EU legislators. It sets the framework for the further development of certification methodologies for projects that aim to remove and store carbon from the atmosphere or to reduce greenhouse gas emissions from biogenic carbon reservoirs, such as peatland rewetting (Chapter 5.1).

In the case of peatland rewetting, it is crucial that carbon certificates are first issued for the reduction of greenhouse gas emissions from the soil considering that the ability of peatland to remove and store carbon depends on the re-establishment of peat-forming vegetation and may not occur until decades after rewetting (von Unger et al. 2019, Wilson et al. 2016). A carbon credit framework for emissions reductions on peatlands should not only include rewetting for nature conservation but also allow for wet usage forms such as solar PV and paludiculture, which is the case in the CRCF Regulation.

B) Supporting the development of markets for paludiculture products

Paludiculture biomass production plays a crucial role for the success of peatland rewetting as it can provide alternative income to farmers and landowners on wet peatlands. Generating this added value would make wet farming more financially attractive, thereby reducing the need for public rewetting payments over time.

The contribution of peatlands to climate change mitigation increases, if paludiculture biomass is used to manufacture long-life products (Lahtinen et al. 2022). The use of biomass for energy production should be avoided if more efficient material use options are available. It is therefore key for policy design to make material use of paludiculture biomass more attractive than its energy use (Chapters 4.2 and 4.7).

Even though some outlets for biomass products already exist, value chains have yet to be created to integrate paludiculture biomass. Developing markets for paludiculture products is therefore necessary. The demand for paludiculture biomass is likely to increase in the near future, as it can contribute to the climate neutrality of other sectors by providing an alternative to emissions-intensive materials, particularly in the construction sector (Agora Industry & Systemiq 2024, Ziegler et al. 2021). Some existing and proposed EU policies will stimulate this demand: for example, the Ecodesign for Sustainable Products Regulation ((EU) 2024/1781), the Corporate Sustainability Reporting Directive ((EU) 2022/2464) and the Net Zero Industry Act (Regulation (EU) 2024/1735). However, a more comprehensive policy mix is needed to accelerate the use of paludiculture biomass and the establishment of value chains. EU policies can support this in several ways:

- By setting an ambitious overall climate target, which will indirectly increase the carbon price and the incentive to use low-emissions materials such as paludiculture biomass.
- By implementing policies that incentivise companies to increase their demand for low-emissions materials. Examples for such policies that are already in place in the construction sector are the Construction Products Regulation ((EU) 305/2011) and the Energy Performance of Buildings Directive ((EU) 2024/1275). Requirements from these policies for measuring and reporting the carbon content of buildings (embodied carbon) can incentivise the substitution of high-emissions materials with low- or zero-emissions materials such as insulation from paludiculture biomass (Agora Industry & Systemiq 2024, Nordt & Dahms 2021). The EU could further incentivise demand by setting a standardised framework to define low-emissions biomass and move towards limit values for embodied carbon (Agora Industry & Systemiq 2024).
- By introducing sustainability requirements in the public sector to create markets for paludiculture

biomass. For example, public procurement could include selection criteria such as the carbon footprint of products and set minimum quotas for the use of low-emissions biomass (Agora Industry & Systemiq 2024). The public sector could act as an exemplary model to stimulate the use of paludiculture biomass.

- By incentivising member states with relevant agricultural peatlands to attribute EU funds, such as from the European Regional Development Fund, to supporting regional value chain development for paludiculture biomass.

4.7 Forest management

4.7.1 Scenario

European forests provide a wide range of ecosystem services (Figure 40). Among other services, forests have the greatest capacity of all forms of land use to store carbon in their biomass and are rich in biodiversity (Biber et al. 2020, EEA 2022b, Soimakallio et al. 2021). As the impacts of climate change intensify, the services provided by forests are becoming increasingly important. At the same time, climate change affects forest growth and increases the frequency of disturbances, thus compromising the provision of services (Patacca et al. 2023). Adapted management strategies contribute to forest resilience under a changing climate and help to preserve these services.

Besides other ecosystem services, forests are essential for wood production. Some 510 million cubic metres of forest wood (under bark; Eurostat 2023h) were harvested in the EU in 2022, a total that has been increasing: the three-year average for 2020–2022 is 23% higher than for 2000–2002. In our scenario, the demand for woody biomass increases by 30% by 2045 compared to 2020, mainly driven by the intention to replace fossil feedstocks with bio-based feedstocks as the economy defossilises (Chapter 4.2).

Wood harvesting, however, affects carbon stocks and sequestration capabilities of forests as well as

Representation of forest services → Fig. 40

Agora Agriculture based on Holzwarth et al. (2020)

other ecosystem services. Managing the different services of forests in a balanced manner is key for aligning wood production with climate change mitigation, the resilience of forests and the protection of biodiversity (Biber et al. 2020). Strengthening forest multifunctionality implies the management of the inherent trade-offs involved, as forests cannot fulfil all the services to their maximum potential simultaneously.

The next two decades will be crucial for climate change adaptation and mitigation. For forest management, this represents rather the short term and the start of a long adaptation process. Therefore, we also take into consideration potential synergies and trade-offs in our scenario for EU forests in the longer term. The forestry aspects of our scenario are not modelled in a simulation model, although certain components, such as the development of forest areas, are integrated into the CAPRI modelling of the agricultural sector (Annex Chapter 8). The scenario includes the following elements for forest management:

A) Adapting forests towards resilient stands
B) Delaying the harvest in targeted forest areas
C) Increasing active afforestation.

We analyse in chapter 4.7.2 and 4.7.3 the ecological and economic impacts of these changes. In Chapter 4.7.4 we discuss EU policy options to incentivise and support the changes outlined in the scenario.

A) Adapting forests towards resilient stands

Adaptation is central to increasing the resilience of forests in a changing climate and to preserving their ecosystem services. Inaction can lead to degraded ecosystems that are less productive, less rich in carbon and biodiversity, and less able to provide other services such as erosion prevention, water retention and local cooling effects.

We approach the need for forest adaptation in the EU based on a literature review on the evolution of potential natural vegetation (Hickler et al. 2012, Hinze et al. 2023). We assume that up to one third of the EU forest area could require adaptation measures by 2045 to counter the effects of climate change, depending on the impact of climate change in the next decades. In our scenario, about half of this area is actively adapted by 2045. This means adaptation efforts will take place on about 1.3 million hectares per year. In these areas, active adaptation means taking action to change the species composition and structures of forests. Action is first needed in stands that already show signs of decline or have suffered from disturbances, such as forest fires, drought and bark-beetle infestations (Patacca et al. 2023). It requires forest genetic resources that are able to deal with future climate conditions. This may include introducing reproductive material from different regions with traits that are suitable for future climatic conditions, and the assisted migration of species or genotypes to

Infobox 6: Prevention of forest fires

2022 was the second-worst year since the start of wildfire registration in the EU in 2000, with 900 000 hectares of natural land affected (San-Miguel-Ayanz et al. 2023). The EU and its member states need to invest significantly in preventing forest fires. Prevention measures at the landscape level are often an efficient way to reduce the consequences of wildfires, which can be even more dramatic if they are followed by heavy rainfall leading to erosion, landslides and floods. Future-oriented forest management should include a wildfire-protection component. The resilience of rural landscapes to fire can be achieved by structuring the space, for example with wildfire-prevention corridors (Miezïte et al. 2023, Neidermeier et al. 2023). It also implies targeted biomass management by landowners and managers to reduce the amount of combustible material, especially around residential areas and public infrastructure.

pre-emptively adapt forests to changing conditions (Chakraborty et al. 2024, Vinceti et al. 2020).

The operational design of adaptation programmes is decisive. They should be developed at the regional level and offer attractive incentives and supportive functions. Knowledge transfer is an important element and can take the form of recommendations such as regional lists or maps for possible tree species and provenances adapted to foreseeable local climate and soil conditions. Implementation programmes are more effective when accompanied by measures to reinforce the capacities of forest-owners' organisations, forestry contractors and tree nurseries. Finally, local cooperation between forest owners and managers and hunters is needed to reduce browsing pressure from game on regenerated areas.

B) Delaying the harvest in targeted forest areas

In our scenario, the demand for biomass for energy and material use is projected to reach 2 900 TWh, increasing by 20% between 2020 and 2045 due to the overall transition of the economy to climate neutrality. This translates into an increase of 30% for woody biomass demand (Chapter 4.2). This additional demand for woody biomass is directed mainly to material use, which increases by 68% of the total woody biomass, whereas the energy use decreases slightly (-4%) (Figure 9). The studies used to estimate the demand for our scenario consider efficiency gains like more efficient production processes, enhanced product design and increased recycling rates, as well as a shift from energy to material use.

Harvest levels are key for balancing the carbon sink service of forests with other ecosystem services, including the production of woody biomass. In the context of a growing demand for woody biomass, the most obvious pathway would be an increase in harvesting in forests, which leads to younger stands, to carbon storage in harvested wood products and increased substitution effects. However, this pathway would have negative impacts on the net forest sink, which outweigh its climate benefits (Soimakallio et al. 2022). The main reason for this is the interplay between forest harvest and sinks and the resulting trade-off situation, as shown in Infobox 7.

In our scenario, we opt for temporarily reducing harvest in targeted resilient forest stands to preserve their growing stock. This translates into a 10% reduction of the overall EU forest harvest (see Infobox 8for measures to achieve this reduction). In practical terms, this takes the form of a harvest postponed by 10 to 20 years compared with the currently planned harvest. All or part of the harvest is postponed, resulting in slightly lower tree growth rates in the medium term in the areas concerned. Combined with the production of additional woody biomass outside forests, this approach makes it possible to balance the increasing demand of woody biomass with climate change mitigation, adaptation and biodiversity protection.

Even though a bigger reduction in the wood harvest might be beneficial from a climate perspective until 2045, it would result in a decline in EU wood processing due to scarcity of raw materials (JRC et al. 2021). Such a harvest reduction would lead to leakage effects, as the shortfall in raw materials and products not produced within the EU would require increased import (Schier et al. 2022). It is likely that a part of such imports would come from third countries with lower levels of control regarding their sustainability including their carbon footprint than in the EU. In addition, a greater reduction in harvesting could have a too negative impact on the future sink after 2045, as it would result in further forest ageing and would limit adaptation efforts.

The 10% reduction in the forest harvest corresponds to a reduction of approximately 50 million cubic metres per year and sets the total annual EU harvest at around 440 million cubic metres. This volume does not include the potential additional harvests resulting from extreme weather events and disturbances, which are challenging to forecast (Patacca et al. 2023, Vacek et al. 2023) and it does not include the harvest resulting from adaptation programmes. According to our adaptation assumptions mentioned above, about 1.3 million hectares per year are actively adapted. Compared to a situation without adaptation, this could amount to an additional harvest of about 25 to 100 million cubic metres per year, depending on the implementation of adaptation measures (Annex Chapter 8).

The available wood on the market thus depends on disturbances on the one hand and on the scale of adaptation programmes on the other. Hence, the 10% harvest reduction can be offset in certain years. Annual EU harvests are expected to experience even greater volatility than in the past.

As our scenario takes into account the global land footprint of the EU economy, we assume for our scenario that imports and exports of roundwood remain stable at 2020 levels. Both are around 50 million cubic metres, with very low net trade accounting for less than 3% of the EU forest harvest. The gap between growing demand and a slightly reduced

Infobox 7: Interplay between forest harvest and carbon sinks

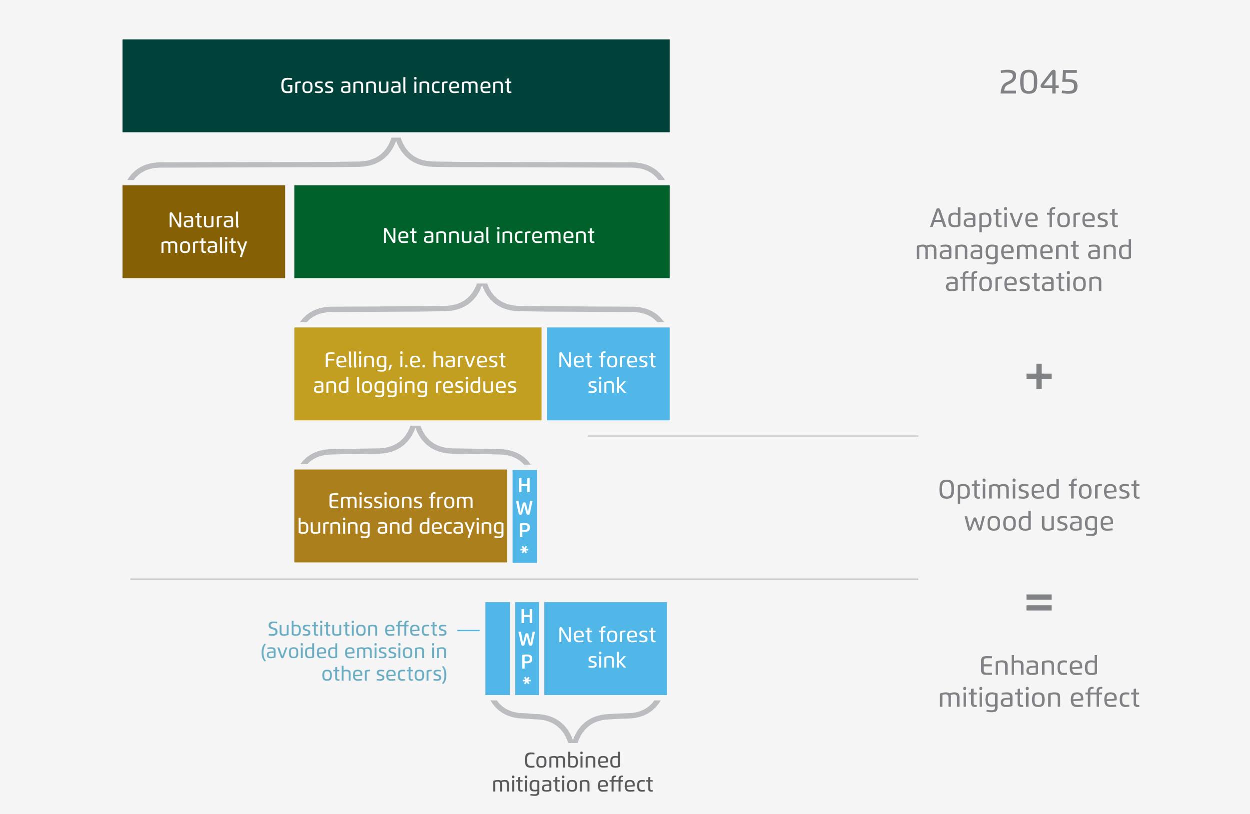
The forest carbon stock refers to the total amount of carbon stored in a forest ecosystem at a given time. The growing stock is the living biomass, that contributes to growth and therefore to carbon sequestration through photosynthesis. The net forest sink is an aggregation of carbon fluxes and is equal to the net amount of carbon dioxide sequestered from and emitted to the atmosphere over a period of time.

On average, 53% of the carbon stored in EU's forests is contained in forest soils (Forest Europe 2020), followed by 36% in living biomass of trees, litter (9%), and deadwood (2%). Carbon stocks in soil, litter and deadwood derive from sequestration through the living biomass (Flechard et al. 2020). The net carbon sink is determined by subtracting the effects of mortality and harvesting from the growth of the living biomass (Figure 35):

- The annual growth of living biomass, also called the gross annual increment, represents carbon sequestration. It depends on tree species and age structure of the stand as well as environmental conditions, which evolve under the changing climate. Increasing disturbances like storms, droughts, fires, pests and diseases lead to higher mortality rates with consequences for the carbon stock and the net annual increment, which is the gross increment less mortality.
- The net annual increment minus the effects of harvesting results in the net forest sink:
  - Harvest affects the net forest sink by reducing the carbon stock that is stored in forests and the part of the increment that stays in forests.
  - Fellings also impact the future carbon dioxide (CO_2) sequestration capacity; in the beginning negatively as very young replacement stands grow more slowly (sequestering less CO_2) than the harvested ones would have; then positively as younger stands grow faster (sequestering more CO_2) than the removed ones would have.
  - Modelling shows that increased harvest reduces carbon stocks for decades (Soimakallio et al 2022).

Part of the harvested wood is transformed into long-life products, reinforcing the **harvested wood product sink**. These wood products can substitute alternatives that are more intensive in greenhouse gas emissions and thus generate substitution effects (avoided emissions in other sectors). The rest decays or is burned, returning its carbon to the atmosphere in the form of CO_2, unless the CO_2 resulting from combustion is captured and stored permanently.

Main components determining the mitigation effect of the forest sector → Fig. 41



Agora Agriculture based on Korosuo et al. (2023). * HWP = harvested wood product sink

forest harvest is filled by sources within the EU. This can be achieved by mobilising alternative wood resources from outside forests. These include mainly wood from agroforestry systems and fast-growing tree plantations (short rotation coppices) (Chapter 4.2) as well as post-consumer wood and wood from landscape maintenance. This opens the possibility of maintaining a stable supply of woody biomass and avoiding further pressure on forest ecosystems within and outside the EU.

The forest sector can contribute to climate change mitigation by storing carbon in forests and in harvested wood products (Howard et al. 2021). The two factors, however, correlate negatively with each other. Harvested wood products contribute EU-wide to an active net carbon sink of approximately 40 million tonnes of CO_2 equivalent ($MtCO_2eq$) per year (European Commission 2021i), being equivalent to only about 9% of the carbon content (CO_2eq) of the wood harvest in 2020. This is complemented by the benefits of material substitution, which are not attributed to the Land Use, Land-Use Change and Forestry (LULUCF) sector but implicitly credited to other sectors, such as energy. They are estimated to reduce emissions by an additional 18 to 43 $MtCO_2eq$ per year (Grassi et al. 2021, Johnston & Radeloff 2019). While there is a general consensus that harvested wood products play a significant role in reducing carbon emissions and contributing to climate change mitigation, uncertainties remain regarding the quantity of carbon effectively stored in harvested wood products (Leturcq 2020). Grassi et al. (2021) point out that the potential advantages of harvested wood products and material substitution cannot fully offset the decrease in the net forest carbon sink caused by increased harvesting. This observation is consistent with the findings from Biber et al. (2020), who emphasised that the extent of greenhouse gas emissions savings is dependent on the type of wood harvested, methods of disposal and its end use, whether for energy production or in the manufacture of wood products (Pingoud et al. 2018). In the future, these savings could be complemented by carbon capture and storage at the end of the product life cycle.

Our scenario increases the contribution of forest biomass to harvested wood products and to substitution effects, due to the shift within forest biomass between energy and material use. The gain for the harvested wood products' sink can be estimated at around 17 $MtCO_2eq$ per year. We also assume the development of new technologies, such as the production of platform molecules for different applications. Data and methods are lacking to assess this potential contribution.

In our scenario, fuelwood use is rather stable and reserved as a priority for applications where a) other renewable energy sources cannot deliver the high temperatures needed, b) other renewable energy sources cannot be stored and delivered to deal with consumption peaks, or c) energy production is

Infobox 8: Implementation options for the proposed harvest reduction in targeted stands

Reducing the harvest in targeted stands can contribute to both objectives: carbon sequestration and biodiversity protection. However, optimising carbon sequestration or focusing on biodiversity should take trade-offs into account. For example, setting aside old stands for biodiversity purposes can lead to the saturation of the carbon stock capacity, and introducing a pure stand of fast-growing trees reduces forest biodiversity (Biber et al. 2020, Soimakallio et al. 2022).

Forests designated for a harvest delay should be selected with a focus on resilience, stability and long-term carbon sequestration potential (Thompson et al. 2009). Important selection factors are, among others, main tree species, species diversity, age structures and forest health. Forests with diverse species and age classes are typically more resilient to pests, diseases and climate change impacts, thereby enhancing their long-term stability and carbon sequestration potential. It would not be effective to set aside ecologically poor, unstable forests with limited carbon sequestration potential (Kowalski et al. 2004).

Delaying the forest harvest can be more effective if it is targeted at specific species or wood qualities. For example, focusing on the reduction of certain hardwood types, often used for bioenergy, could be valuable. The deciduous climax stands can sequester and store carbon over longer periods, so delaying their harvest can contribute to climate change mitigation. On the other hand, softwood suitable for the construction sector offers long periods of storage and therefore should not be targeted. This approach acknowledges the different roles and carbon sequestration potentials of various forest types and provides guidance on harvesting decisions. Furthermore, targeted reductions can help to maximise ecological benefits while ensuring that the demands of different sectors such as bioenergy and construction are met (Vizzarri et al. 2022).

Measures to postpone harvesting can take the form of voluntary, temporary and rotating harvest reductions (e.g., for one or two 10-year periods). Incentives to reduce harvesting should be tailored to avoid deadweight effects in stands with low growth rates or with high risks of non-permanence. The incentives should reflect these risks, providing greater incentives for managing stands with higher permanence potential and lower incentives for riskier stands (Tedesco et al. 2023). Finally, they should take into account the potential impact on local forest-based industries, avoiding concentrations of implementation in their supply areas.

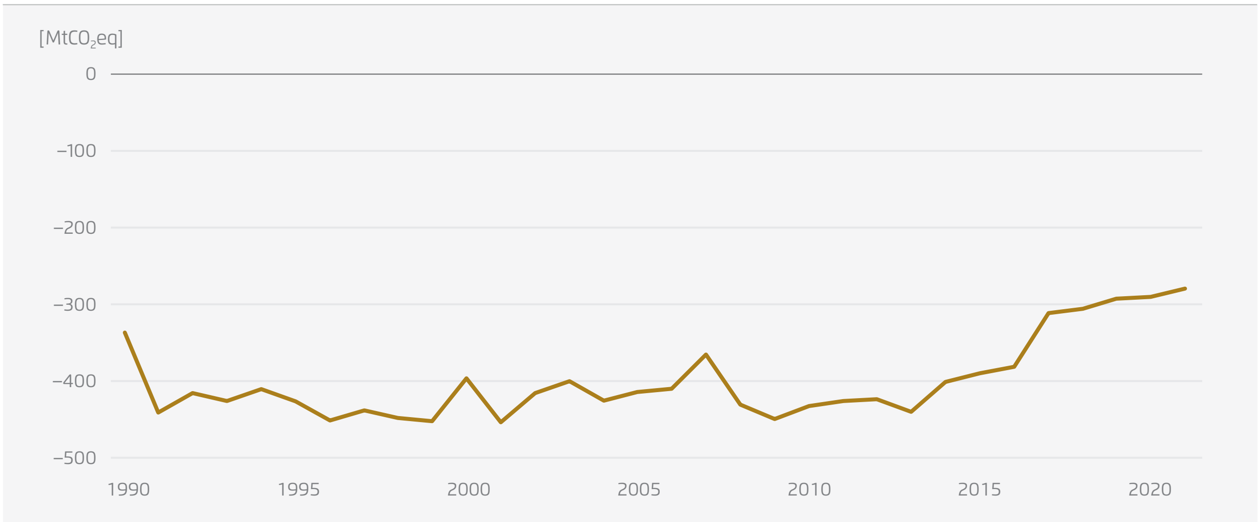
combined with carbon sequestration and storage. It is sensible to avoid burning forest wood, especially when it could be turned into long-life products that could be potentially recycled before being burnt at the end of their life cycle. In the medium and long term, this should result in more efficient processing chains for traditional uses of wood and the development of new value chains to process intermediate qualities and co-products, which are currently burned. A shorter-term strategy may be to redirect these feedstocks into sectors such as particle board, engineered wood products or wood-based insulation.

All in all, our scenario generates significant gains in the forest sink, while preventing leakage effects to non-EU countries. We assume that the annual sequestration level in forests (including afforestation) could be approximately 290 $MtCO_2eq$ in 2045, which corresponds to the 2020 net negative emissions from forest land (Figure 42).

Maintaining the 2020 sequestration level seems a reasonable assumption given the significant efforts needed in forest management and the increasing negative impacts of a changing climate on forests. However, this assumption is uncertain because the effects of climate change on forests are difficult to predict. The uncertainty lies in how climate change will affect forest growth (Nabuurs et al. 2017) since it simultaneously influences productivity and changes disturbance patterns. Recent years have underscored the vulnerability of forests to disturbances, such as severe droughts, wildfires, intense storms and rapid infestations with pests such as bark beetles (Seidl et al. 2017). These disturbances affect the immediate health of forests and their capacity to act as carbon sinks in the long term (EEA 2017). Simulations reveal that disturbances may exacerbate ongoing productivity declines or negate any productivity gains brought by climate change (Reyer et al. 2017).

Assuming the continuation of forest management practices under a changing climate, Pilli et al. (2022) project the absorption capacity of EU forests (including the UK) to decline to approximately 250 $MtCO_2eq$ per year by 2050 and further to around 80 $MtCO_2eq$ per year by 2100. Böttcher et al. (2021), in contrast, show a wide spectrum of potential scenarios, with net removal estimates ranging from 244 to as much as 787 $MtCO_2eq$ per year by 2050. Pilli et al. emphasise the progressive ageing of EU forests as one primary factor influencing the long-term trend of the forest carbon sink. Importantly, our scenario includes afforestation and active management of most EU forests combined

Net CO_2 removals from total forest land in the EU-27 between 1990 and 2021 → Fig. 42



Agora Agriculture based on EEA (2022a)

with adaptation efforts, contributing to the regeneration of older stands and expansion of forests with young stands. The postponed harvest in targeted areas through temporary measures has little impact on the overall ageing.

C) Increasing active afforestation

Afforestation, the creation of new forest areas, contributes to maintaining and enhancing forest services. As climate change threatens different existing forest ecosystems, new forest areas can act as reserves for the future, compensating for the loss or degradation of forest ecosystems that cannot adapt to new climatic conditions. Given the long lead times in the forestry sector, these new forest areas need to be established now to complement existing stands in the second half of the century.

In our scenario, we assume that forests continue to expand, adding 5 million hectares to the EU forest area by 2045. This development happens on former agricultural land and contributes to making the best use of less productive land. The establishment of short rotation coppices can be considered more efficient than afforestation from a wood production and carbon sequestration point of view. Our scenario already includes a strong development in this direction (Chapter 4.2). However, short rotation coppices do not offer the same potential value of services in the long term such as timber quality, biodiversity levels or other regulating and provisioning services.

The 5 million hectares correspond to the forest area trend of the period 2010–2020 (Eurostat 2023c). A significant part of this trend results from abandonment of agricultural land with a spontaneous growth of pioneer tree species. Well-designed afforestation can lead to more resilient forest stands with the potential to adapt to future climatic conditions. Active afforestation can be based on full plantations or rely initially on natural successions, with subsequent management to achieve an appropriate structure and species mix. Further, planning afforestation with a landscape-level approach can help maximise benefits (Salbitano et al. 2016).

4.7.2 Environmental and climate impacts

Carbon sequestration

The uncertainties of climate change impacts on carbon sequestration make it difficult to quantify the potential gain from adapted forest management on the potential for carbon removal from forests (vonHedemann et al. 2020). These challenges pertain to both the scientific understanding of carbon dynamics in forest ecosystems and the methodological approaches used to assess them.

- Using the carbon balance indicator from Soimakallio et al. (2022), we estimate an annual sink gain from the reduced harvest of approximately 30 $MtCO_2$ per year (Annex Chapter 8).

The adaptation measures in our scenario have a negative short-term impact on the forest sink but are necessary to ensure sequestration in the future. The magnitude of this short-term impact is dependent, for example, on harvest intensity.

- The 5 million hectares of newly afforested stands in our scenario result in an additional sequestration of approximately 20 $MtCO_2eq$ per year by 2045. This rough estimate is based on a side calculation with emission factors (Annex Chapter 8).
- The gains from the afforestation and the harvest reduction amount together to 50 $MtCO_2eq$ per year by 2045 and allow to counter the current declining trend of the forest sink. These gains might be reduced or offset, in certain years, by additional harvesting resulting from adaptation measures and calamities (Annex Chapter 8).
- By adding these gains to a modelled value of the forest sink for 2045[63] under climate change (Pilli et al. 2022), we obtain a forest sink value of 290 $MtCO_2eq$ which is equivalent to the 2020 value.
- In addition, the annual harvested wood product sink increases by an additional 17 $MtCO_2eq$ to a total of 58 $MtCO_2eq$ in 2045 due to a shift from energy to material.

63 Average value for representative concentration pathway scenario 2.6, assuming the continuation of the management practices applied between 2000 and 2015: 240 $MtCO_2eq$.

Biodiversity protection

Biodiversity gains in forests from our scenario depend largely on management choices regarding forest adaptation and afforestation. We aim to balance the different ecosystem services and do not focus only on production and carbon sequestration. Adaptation and afforestation measures support forest biodiversity if diversity in tree species, in structure as well as in management intensity is considered. Further, they should cater for enough dead wood and habitat trees.

The biodiversity benefits of postponed harvest depend on several factors, including the methods used for the reduction process and the types of forests affected. For example, research has shown that targeted reductions in logging activities in older forests, which tend to be rich in biodiversity, can result in more substantial gains for species conservation compared to the same action in younger or less diverse forests (Chaudhary et al. 2016). However, the biodiversity effect eventually depends on local ecological conditions and species-specific requirements (IUCN 2020, WWF 2023).

4.7.3 Socio-economic impacts

In our scenario, forest owners are expected to maintain or enhance the ecosystem services of their forests and thus produce public goods. At the same time, they continue offering commercial goods, mainly wood. Locally, non-wood forest products such as mushrooms, berries, nuts or hunting contracts can provide additional income. While wood production remains central to the profitability of forestry during the upcoming decades, wood sales alone cannot reward forest owners for the services expected by society, such as carbon sequestration and biodiversity (Felix et al. 2022). Rewarding forest owners for adjusting their management practices or remunerating them for the ecosystem services opens new income opportunities.

Adapting forests towards resilient and adaptive stands

Adapting forests to climate change is costly. Various studies come up with a corridor between 4 300 and 15 000 euro of investment needed for the adaptation of one hectare of forest in Germany (Bolte et al. 2021, Umweltbundesamt 2016). The adaptation measures of our scenario would thus cost around 260 billion euro until 2045 or roughly 12 billion euro per year if adaptation efforts are started in 2025. In comparison, forest management and logging activities generated a gross added value of 25 billion euro in the EU in 2021. The cost of forest adaptation may therefore not be put on forest owners alone, but partially be borne by society at large, as forest resilience is a societal investment with many public benefits.

Reducing forest harvest rates in targeted areas

Reducing or postponing forest harvest in stable stands implies a longer immobilisation of wood capital and a longer period during which the stand is subject to biotic and abiotic hazards. The associated costs for the forest owners can represent a significant part of the overall added value and depends on multiple factors such as tree species, wood qualities and market and logging cost dynamics.

Based on the average growing stock per hectare of forest in the EU, we estimate roughly the area required for the 10% reduction of the EU harvest in our scenario (Annex Chapter 8). Assuming a commitment period of 20 years (or 10 years renewed), this translates into postponed harvesting on 5% of the EU forest area. The area needed is higher if shorter commitment periods are assumed and lower if the measures are applied on stands with higher growing stocks than in the EU on average.

Increasing afforestation

Unlike spontaneous afforestation, which develops progressively on abandoned land through pioneer species, active afforestation involves land-use change, usually from agricultural land. This can imply significant opportunity costs for the landowner. We assume that areas selected for afforestation will be less suitable for agricultural production, which limits the opportunity costs. However, the investment cost for afforestation, depending on the species mix and establishing practices are high, for example between

12 000 and 35 000 euro per hectare in Germany today (Offer 2020). They include soil preparation, seedlings, materials, workforce, young tree care and possibly fencing. Assuming that half of the 5 million hectares of new forests are the result of active afforestation between 2025 and 2045, the investment cost could be between 2 and 3 billion euro per year.

4.7.4 Policy options

Realising the climate change mitigation potential of forests during a time of increasing demand for woody biomass and acknowledging the multiple services of forests requires a comprehensive policy mix. Today, forest governance in the EU operates under national jurisdiction. However, EU policies affecting forests span several domains, including climate, energy, agriculture and environment. The lack of alignment between these policies leads to limited effectiveness in dealing with trade-offs and optimising synergies. For example, high renewable energy targets, to which fuelwood can massively contribute, are counterproductive in relation to targets set for the LULUCF sector, for which the forest sink is the main component.

In this section, we provide an outlook on how EU policies could better contribute to optimising the role of climate change mitigation through the forest sector:

A) Forests as part of the future EU climate policy
B) Incentivising the material use of wood in long-life products

A) Forests as part of the future EU climate policy

The EU climate policy is important for incentivising and financing forest adaptation, afforestation and sustainable management practices to preserve the current forest sink. Forest carbon sequestration and storage services already deliver and remain relatively low-cost solutions among the carbon removal options in the short and medium term. However, preserving these removals requires significant investments, and funding is needed to reward forest owners for maintaining and enhancing the ecosystem services of their forests, including carbon sequestration, water retention or biodiversity conservation.

Such funding can come from different sources. For example, the Common Agricultural Policy (CAP) already provides the opportunity to support forest owners but only on a very limited scale. Revenues from the EU Emissions Trading Systems (EU-ETS) are another option. Member states can already use these to finance investment in improved forest management and afforestation activities. In addition, the forest sector could benefit from the revenues generated by a future ETS for agriculture and agricultural peatlands (Chapter 5.1). Theoretically, including carbon removals by forests in an ETS would generate incentives to invest in such removals. However, there is a risk of a potential mitigation deterrence if carbon removals by forests could be used to offset emissions that would otherwise have been avoided. This is particularly relevant, since carbon removals by forests are not permanent. Therefore, it appears important to handle emissions mitigation separately from removals in the land use sector in EU climate policy. Revenues from an ETS could be used to reward forest owners for their contributions to negative emissions.

Voluntary carbon markets are another financial source for rewarding the carbon removal services of the forest sector. Voluntary carbon markets are attractive because they supplement mandatory mitigation pathways, especially in the period when the land use sectors are not yet included in carbon pricing. Such carbon markets have undergone a new phase of development in recent years to meet the demand from companies that have set themselves climate targets. Recently, these markets have been rocked by scandals, calling into question the environmental integrity of major forestry projects. Therefore, they need to be regulated and closely monitored to ensure trust in certificates and avoid abuses that have been observed. Importantly, the EU has started regulating both the quality of voluntary carbon certificates through the Carbon Removals and Carbon Farming (CRCF) Regulation (2022/0394(COD)) and their use by companies with the future Green Claims Directive (2023/0085(COD)). Voluntary carbon markets represent an opportunity for EU forest owners, as removal certificates from EU forests appear particularly attractive for EU companies, especially when they demonstrate co-benefits, for example in terms of biodiversity (Munzel et al. 2024).

Sustainable finance can be an alternative source of private support. The EU Taxonomy Regulation ((EU) 2020/852) recognises forest management as an activity that contributes to climate change mitigation, focusing on the contribution of forests and forest products to carbon sinks. It also encourages property investors to use more wood products in the construction or renovation of buildings.

Further, the EU climate policy provides the space to set the levels of ambition (Chapter 5.1) for forest carbon removals. We consider the definition of a separate target for forest carbon removals as an important option to increase the political focus on the carbon services of forests. This could also be undertaken at member state level. However, setting such a target is challenging due to the high level of uncertainties regarding the effects of climate change on forest carbon removal potentials. Acknowledging this requires flexibility mechanisms and regular reviews to react to the increasing volatility of future forest harvests.

For forest owners, the policy mix needs to provide long-term orientation. Because of the strong contribution of forests, the learning processes inherent in any new management approach and the long response time of forest ecosystems, the development of public and private governance mechanisms are a matter of urgency and should have a high priority during the current EU legislative cycle.

B) Incentivising the material use of wood in long-life products

The contribution of the forest sector to climate change mitigation increases if woody biomass is used less for energy production and more to manufacture goods, especially long-life products. Today, technical limitations, renewable energy targets and price signals are directing more than half of the harvested wood (including harvested wood and secondary products such as bark and by-products) and some post-consumer wood to bioenergy applications (EEA 2023d). To encourage the material use of forest biomass, it must be more attractive than its energy use. This can be supported by different measures.

One option is to reduce the incentives for forest bioenergy. Under the EU-ETS, burning woody biomass is counted as carbon neutral. Hence, no carbon price applies to the released emissions. Under this zero-rating rule, an increasing carbon price even increases the incentive to burn woody biomass. The main rationale behind this rule is the cycle of biogenic carbon. CO_2 emitted by the combustion of wood harvested from a sustainably managed forest is potentially recaptured by this forest in the future. A complete recapture nevertheless takes decades to be effective. Meanwhile, the CO_2 that remains in the atmosphere causes significant radiative forcing. Therefore, the assumed carbon neutrality of the combustion of forest wood does not reflect the physical reality and its impact on the climate (Mathias & Robert 2020).

In conclusion, the EU's current position on bioenergy from woody biomass from forests should be critically examined (Selivanov et al. 2023, Souza et al. 2017). This includes a reassessment of the accounting rule that assumes that wood combustion is carbon neutral, as well as a revision of the role of forest biomass in the targets and sustainability criteria of the Renewable Energy Directive ((EU) 2018/2001). Revising these provisions would affect the market dynamics and economic viability of practices in the forest sector such as the combustion of coproducts to dry sawn wood, unless exceptions are granted for those applications. The revision of the zero-rating for woody biomass should lead to differentiated pricing based on the carbon opportunity costs of the different types of woody biomass (Chapter 4.2) taking into account the lower energy density of biomass compared to fossil fuels, which could favour the latter in a ystem with a single carbon price.

Using wood for energy can be an efficient solution, especially when options for material use are limited and energy use creates benefits, such as substituting fossil fuels, limiting energy dependency, developing local value chains or generating high temperature for industrial processes. The aim is therefore not to eliminate using wood as an energy source, but to phase it out gradually where more sustainable alternatives exist.

Other policies to encourage material and long-life usage of wood include:

- **Remunerating carbon storage in long-life wood products.** Some examples of such policies exist at regional scale (Bayerisches Staatsministerium für Wohnen, Bau und Verkehr 2021). In addition, the CRCF Regulation opens the possibility of certifying carbon storage in long-life applications such as wood used by the construction sector in structures. This could be completed by measures aiming at removing the barriers to the use of wood in construction, i.e., adapting regulation and standards to wood specificities.
- **Promoting a cascading use of wood products**. Adhering to circular economy principles is not entirely possible for a raw material like wood as it can be recycled only a finite number of times. However, adopting cascading-use principles can help to optimise the value and lifespan of wood products. Prioritising higher-value applications of harvested wood before recycling or energy production minimises greenhouse gas emissions as well as waste. In concrete terms, this could include incentives to develop alternative hardwood value chains, better product design and practices to facilitate reuse and recycling, or to divert a greater proportion of sawmill by-products to the panel industry. Strengthening collecting and sorting capacities, as well as providing information on the products available for re-use, are important aspects of this cascading strategy.
- **Adapting to the future volatility and composition of the forest harvest.** Investments could also encourage investments along the value chain to better absorb fluctuations and ensure higher value for additional volumes. This includes reinforcing capacities in forest harvesting, wood transport and storage. The processing industry could also be supported to include in its business models a higher use of salvage wood and hardwood, which will be produced in greater quantities in the future.

5 Cross-cutting policy priorities for the 2024–2029 EU legislative period and beyond

During the previous legislature, the European Green Deal and its accompanying Farm to Fork Strategy presented a comprehensive set of objectives and a package of measure to advance climate, environmental, health, consumer protection and animal welfare goals. However, many of the initiatives affecting the food and land use sectors presented or announced under this package were strongly contested. While aspiring to address existing environmental and social challenges, the European Green Deal may have fallen short in offering sufficient opportunities for land users.

There is a strong rationale for enhancing the contribution of agriculture and forestry to societally agreed sustainability objectives (Chapter 3). Realising this potential will, however, be demanding. An important task for the 2024–2029 EU legislative cycle will be to ensure that further steps in the transition towards more sustainability are accompanied by economic and social opportunities and a fair distribution of the costs involved.

We consider this legislative period to be crucial for strengthening the ability of farmers, forest owners and rural entrepreneurs, as well as consumers, to actively contribute to sustainability objectives. This requires a long-term commitment from policymakers and an integrated policy mix to create enabling environments for an efficient use of land and a sustainable consumption of food, feed and other biomass.

The "Policy options" sections in Chapter 4 discuss elements of an enabling policy environment, summarised in Figure 43. In this chapter we articulate some of the underlying considerations that have guided us in proposing these policy options.

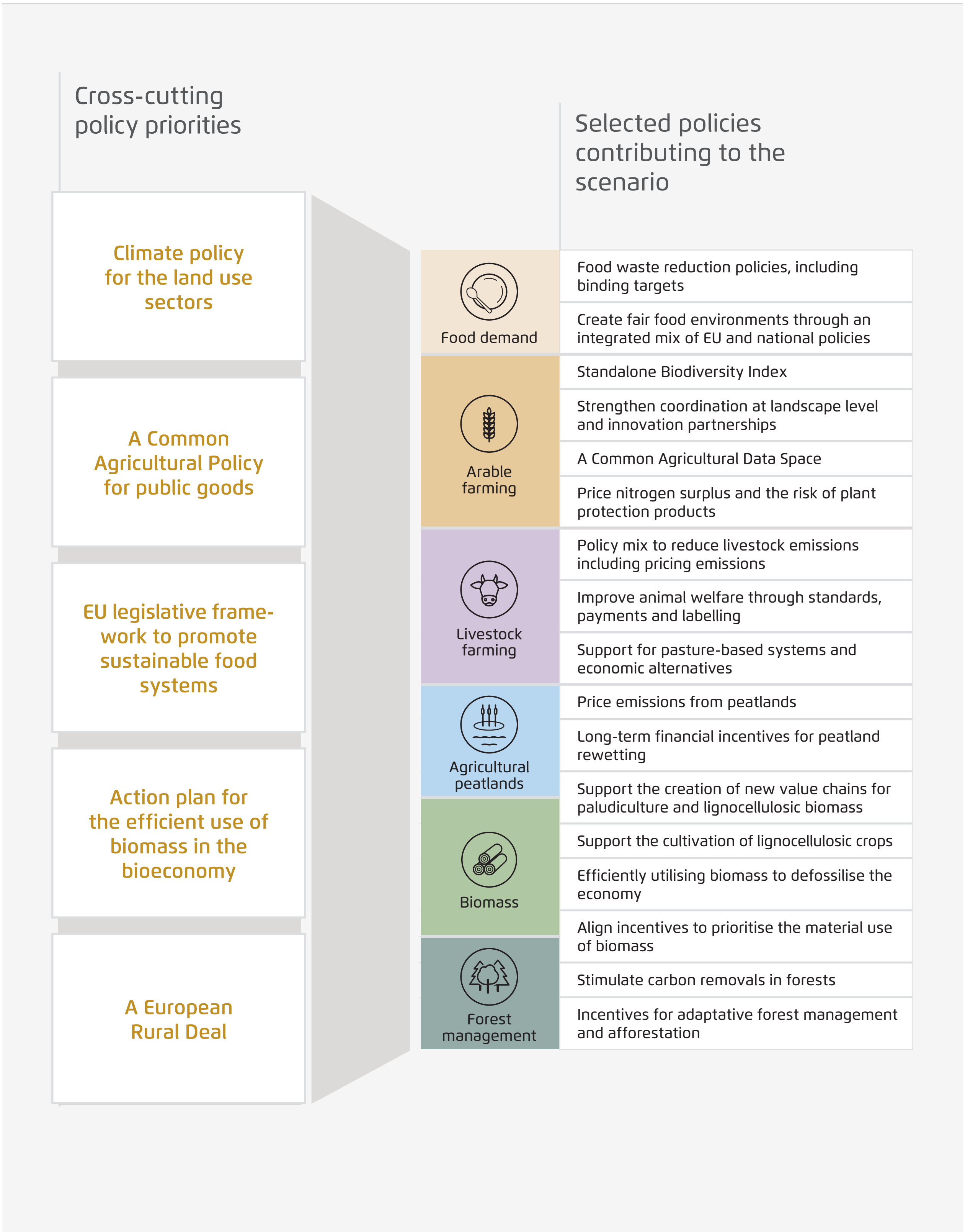
Furthermore, this chapter describes five cross-cutting policy projects. These can act as building blocks for an EU policy framework for the land use sectors, food system and bioeconomy during the 2024–2029 EU legislative period and beyond. Some of these priorities described below are more evolved, while others, despite their relevance, are still in an early stage of development:

1. A Climate policy for the land use sectors,
2. A Common Agricultural Policy for public goods,
3. An EU legislative framework to promote sustainable food systems,
4. An action plan for the efficient use of biomass in the bioeconomy.
5. A European Rural Deal.

The policy mix proposed in this study relies on several guiding considerations. Most importantly, farmers, forest owners, rural communities and consumers need policy environments that enable them to contribute to societally endorsed sustainability objectives. For economic actors, policy predictability is important for planning security. Binding targets and objectives provide clarity about the policy aims pursued and can help mobilise long-term political commitment. Key policy areas where we identify the importance of target-setting include climate policy (5.1), biodiversity protection (3.2 and 4.5) and food waste reduction (4.3). The proposed Legislative framework to promote sustainable food systems (5.3) and an EU Action Plan for the efficient use of biomass (5.4) also serve to provide clarity about the long-term objectives for the food system and the bioeconomy.

Rather than relying on command-and-control regulation, market-based instruments play an important role in our policy mix. By setting the right economic incentives, such policy measures offer greater flexibility for economic actors to find appropriate management solutions, thereby safeguarding entrepreneurial options. For example, carbon pricing internalises the societal costs of greenhouse gas emissions into products and services, sending price signals across supply chains. This reduces the

A policy mix for the land use sectors, food demand and biomass in the bioeconomy → Fig. 43



Agora Agriculture

profitability of carbon-intensive activities. At the same time, it stimulates new demand structures, such as the use of biomass to replace fossil carbon in construction. This creates opportunities for farmers, forest owners and rural entrepreneurs to supply new market demands (Chapters 4.5, 4.6 and 4.7). To realise such market opportunities, policy attention will be required to support the development of new value chains and the adoption of new technologies (Chapters 4.2 and 5.4, 5.5).

The land use sectors have a major role to play in providing public goods, such as carbon sequestration, protecting biodiversity or improving animal welfare. Generally, there are two options to incentivise the provision of public goods in open markets while preventing production from relocating to third countries: through domestic regulation accompanied by trade measures that establish reciprocity in production standards, or through payments for the provision of public goods (Chapters 3.5 and 5.2). Trade measures come with political challenges in relations with trade partners and should be used sparingly. For example, carbon border adjustments could be restricted to certain goods (Chapter 5.1). Therefore, the study consistently highlights the importance of public payments as a means of supporting the provision of public goods. Public payments will be a critical component of more sustainable business models in the land use sectors (Chapter 4.1). However, in the context of scarce societal resources, such money needs to be spent efficiently. Furthermore, a fair division between public and private responsibility for contributing to societal objectives needs to be negotiated. A targeted spending of money under the Common Agricultural Policy (CAP) to reward farmers for public goods is an example of this approach (Chapter 5.2), as well as animal welfare payments (Chapter 4.4).

Enabling conditions are needed for consumers. The sustainability benefits associated with our scenario, ranging from climate to health to biodiversity, are largely made possible by changes in food demand. We consider the creation of fair food environments to be a key measure for making healthy and sustainable food choices easier and more affordable for consumers (Chapter 4.3). While fair food environments depend on several policy measures and instruments, regulatory standards can be important for securing specific levels of consumer protection. They can simultaneously also help create a level playing field for economic actors across the EU. Examples of this include the regulation of children's exposure to food marketing on digital and other media, or the labelling of food products (Chapter 4.3).

Finally, in designing land use and food policies, the governance level best suited for defining objectives and targets, as well as the design, implementation and funding of policy instruments, needs to be considered. Given the wide diversity in social, economic, ecological and administrative contexts across EU member states, the details of instruments to govern the land use sectors and food environments are often best designed at national, and sometimes regional and local levels.

The EU provides a governance space well-suited for the formulation of common objectives, targets and wider policy frameworks. When appropriately designed, such frameworks, like the CAP or the Legislative framework for sustainable food systems, enable countries to move in a similar direction while maximising flexibility in implementation. For certain instruments, application across the EU can contribute substantially to a level playing field for economic actors, efficiency of regulation and reliability of policy development. This is exemplified by the potential implementation of an emissions trading system for greenhouse gas emissions from agriculture and agricultural peatlands (Chapter 5.1), or by introducing improved EU animal welfare standards (Chapter 4.4).

5.1 Climate policy for the land use sectors

The design of a post-2030 climate framework will be one of the most consequential political processes of the 2024–2029 EU legislative period. The European Commission is expected to propose a climate target for the EU for 2040. It is also likely to present a set of policy measures aimed at achieving this target.

Four aspects are especially relevant for the design of a climate governance framework for agriculture and forestry:

A) The definition of an appropriate level of ambition for the contribution of the land use sectors to climate neutrality
B) The translation of this level of ambition into climate targets
C) The design of a framework to govern emissions from agriculture and agricultural peatlands
D) The introduction of credible incentives for land-based carbon removals

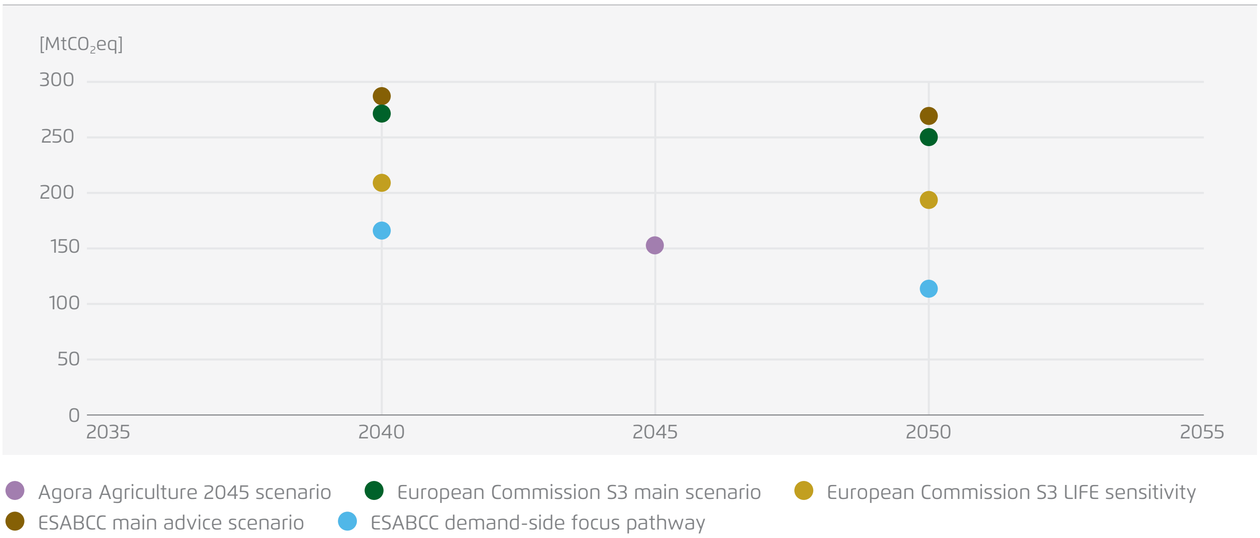
Moreover, the land use sectors are highly sensitive to the effects of climate change. Special action is therefore required to enhance the resilience of agriculture and forestry in the face of accelerating climate impacts. In the coming years and decades, adaptations in land use patterns, management practices and technologies will be necessary to prevent climate risks from jeopardising livelihoods and cascading across society (EEA 2024a) (Chapters 4.5.1 and 4.7.1). Many options exist to implement measures that combine climate adaptation, mitigation and biodiversity benefits (EEA 2021).

A) Level of ambition

The starting point for a climate policy for agriculture and forestry beyond 2030 is to define an appropriate contribution these sectors should make towards achieving climate neutrality. Agriculture is expected to be the sector with the highest residual emissions in the EU in 2050 (European Commission 2024b). The size of these residual emissions and the overall role of the land use sectors in the transition to climate neutrality are subject to societal negotiations. The definition of an appropriate level of ambition until 2050 depends on a range of factors. These include the feasibility of reducing emissions form agriculture and agricultural peatlands, the expected level of residual emissions across the economy, and the technical potential and costs associated with compensating for these emissions through carbon removals.

We present a scenario that results in greenhouse gas emissions from agriculture and agricultural peatlands declining by about 60% between 2020 and 2045, resulting in around 186 million tonnes of CO_2 equivalent ($MtCO_2eq$) in residual emissions (Chapter 4.1). This outcome provides an orientation for setting the level of ambition for emissions reductions from agriculture within the EU climate framework.

Comparison of different scenarios of agricultural emissions projections → Fig. 44



Agora Agriculture based on CAPRI results, European Commission (2024b), ESABCC (2024)

Other models and analyses also envision significant reductions in agricultural emissions by 2040 or 2050 (Poux & Aubert 2018, Lóránt & Allen 2019, ESABCC 2023, European Commission 2024b). These scenarios all outline a reduction potential that exceeds current greenhouse gas emissions projections by member states (EEA 2023b).

Figure 44 compares our scenario with recent modelling conducted by the European Commission (2024b) as well as an analysis by the European Scientific Advisory Board on Climate Change of a range of scenarios from different modelling exercises (ESABCC 2023, 2024). The comparison covers only emissions from agriculture, not including agricultural peatlands. On top of the main scenarios, both analyses show projections for pathways in which food demand changes significantly.[64] The comparison shows the unexploited potential of emissions reduction in main scenarios which do not capitalise on the opportunities provided by changes in patterns of demand.

Regarding carbon removals, considerable uncertainties exist about the potential of both technological and land-based sinks.[65] In our scenario, forests are estimated to provide net carbon removals of approximately 290 $MtCO_2eq$ in 2045, which we consider optimistic. We estimate removals by harvested wood products to increase to approximately 58 $MtCO_2$ by the same year from 41 $MtCO_2$ in 2020. Fast-growing trees established on agricultural land are estimated to provide carbon removals of around 30 $MtCO_2$ on average annually between 2025 and 2045. In addition, we assume the planting of hedgerows on agricultural land to sequester on average 5 $MtCO_2$ per year in the same period. (Chapter 4.1). Other projections estimate the potential for total land-based net removals to lie in a range between 100 and 400 $MtCO_2eq$ per year by 2050 (ESABCC 2023).

We consider these estimates for both emissions reductions and removals to be an appropriate starting point for discussions on climate ambition and setting targets for the land use sectors. Beyond the expected levels of residual emissions and the performance of carbon removal options, there are other factors to consider when defining the contribution of the land use sectors to mitigating climate change. These include the mitigation costs and societal preferences about the equitable distribution of responsibilities between the land use sectors and the rest of the economy. Other aspects include whether carbon leakage to third countries is accounted for, and the potential benefits and trade-offs of different climate change mitigation scenarios, such as the land made available for a more sustainable bioeconomy, improving biodiversity and animal welfare, and reducing diet-related diseases.

B) Targets for the land use sectors

Translating the level of ambition into a set of binding targets is a precondition for a long-term predictable climate policy. Establishing an EU-wide net greenhouse gas emissions reduction target for 2040 alongside an overall target for carbon removals is a necessary starting point. Subsequently, to clarify and better steer the contribution of the land use sectors to mitigating climate change, we consider the following sub-targets to be relevant in a future climate framework:

- **A dedicated EU emissions reduction target for agriculture** would clarify the sector's contribution to overall emissions reductions. Such a target can be codified in an updated Effort Sharing Regulation ((EU) 2018/842). At the same time, given that agricultural peatlands are an integral part of the agricultural holding and farm management decisions, there is benefit in going beyond the scope of an agricultural target by also including agricultural peatland emissions. Setting an emissions reduction

64 European Commission LIFE sensitivity analysis and ESABCC demand-side focus pathway.

65 Land-based removals are accounted under the Land Use, Land-Use Change and Forestry (LULUCF) sector. Land-based removal activities include afforestation, sustainable forest management, a range of agroforestry options, storage in mineral soils (in grasslands and croplands), and storage in rewetted organic soils (although rewetted peatlands may start sequestering carbon again only after decades (Chapter 4.6). Carbon storage in wood products is also included in LULUCF accounting. Biochar and Bioenergy with Carbon Capture and Storage (BioCCS) are not land-based removals but are closely related to the land use sectors; they can have major impacts on land use and need to be carefully managed (Chapter 4.5 and CONCITO (2023)).

target that covers emissions from both agriculture and agricultural peatlands would consider core farm-level activities together. Such a target would need to be made coherent with a climate framework for the Land Use, Land-Use Change and Forestry (LULUCF) sector, under which agricultural peatland emissions are covered (Chapter 4.6.4).

- **A separate overall target for carbon removals** will be an important addition to an EU-wide net emissions reduction target (Agora Energiewende 2024, NEGEM Project 2023, Carbon Gap 2024). Such a target will incentive removal activities, while defining the relative contributions of removals and emissions reductions to climate change mitigation. Setting separate sub-targets for land-based removals, corresponding to the LULUCF sector, and for technological removals may be important to consider. Such as division would provide a clear perspective for policymakers and market actors about the relative roles of each of these removal strategies.
- **A net removals target for forests**, as a sub-target of a wider LULUCF removals target, would give visibility to the important role of forests in carbon removals and acknowledge the uncertainty involved in forest development under climate change. Forests provide the EU's largest carbon sink and are currently under threat due to the impacts of intensifying climate change. A forest target would help mobilise resources for forest-management strategies that support their potential to remove carbon.
  Such a target for forests must consider the impact of climate change on forests, including the consequences of natural disasters, the need to adapt specific forest types, as well as the increasing demand for woody biomass as the economy transitions to climate neutrality. These aspects will determine how much carbon European forests can sequester and the balance between harvesting wood and the forest sink. For example, an overly ambitious removal target would require strongly reducing the harvest levels, given that other measures such as afforestation have limited capacities and long implementation periods. With increasing demand for wood, this could lead to increasing imports and hence to leakage despite some recent safeguards, such as under the Regulation on Deforestation-free products ((EU) 2023/1115). Long-lasting harvested wood products also contribute to storing carbon sequestered by forests. However, due to carbon losses along the value chain, a gain in the harvested wood products sink from increased harvesting does not compensate for the corresponding loss in the forest sink (Chapter 4.7.1).

Target-setting can also be used to communicate about the wider role of land use in climate change mitigation:

- For example, the option of a net target for the combined Agriculture, Forestry and Other Land Use (AFOLU) sectors continues to be debated.[66]
  A long-term net-negative AFOLU target would signal the important role that agriculture and forestry in the EU can play for climate neutrality, while continuing to supply critical societal needs such as producing food, feed and other biomass, and protecting biodiversity. The main drawback of such an AFOLU target without sub-targets for agriculture and agricultural peatlands is the uncertainty related to the future sink potential of forests. Creating an interdependency between forest sinks and agricultural emissions risks, on the one hand, requiring too great an effort from agriculture if the forest sink cannot be maintained. On the other hand, well-performing sinks could disincentivise emissions reductions from agriculture.
- A net target could also be established for Agriculture and Agricultural Land Use (AALU). Such a target would communicate a vision about the greenhouse gas balance that can be achieved within the agricultural sector. This target would include emissions reductions from agriculture and agricultural peatlands, as well as net carbon removals from agricultural land use. Unlike with a combined target with forestry (AFOLU), this approach would avoid creating interdependencies between forestry and agriculture. A separate legal framework for the remaining LULUCF land uses, including forests, would still be required.

66 In terms of climate inventories, AFOLU would mean greenhouse gas emissions and carbon removals from LULUCF plus emissions from agriculture.

C) Governance of emissions from agriculture and agricultural peatlands

An effective policy strategy to reduce emissions from agriculture and agricultural peatlands should simultaneously lower the emission intensity of production activities, achieve a reduction in greenhouse gas-intensive production activities and decrease demand for greenhouse gas-intensive products (ESABCC 2024). Traditionally, it has been argued that emissions from the agricultural sector and food consumption should be addressed by a mix of targeted regulatory and fiscal policies (e.g., WBAE & WBW 2016). These can include, for example, climate payments for rewetting agricultural peatlands, pricing policies such as carbon or consumption taxes and regulatory standards on nutrient balancing.

Although theoretically appealing, in practice only limited progress has been made in implementing such a policy mix. At the EU level, achieving political consensus for such a mix of measures will be challenging, particularly due to the unanimity requirement for taxation measures. At the level of individual member states, advancement on any of these measures has so far been inconsistent and slow. Denmark is the only country in Europe considering the introduction of a carbon tax on agricultural emissions (Statsministeriet 2022) (Expert Group for a Green Tax Reform 2024).

Implementing an EU-wide Emissions Trading System (ETS) for agricultural emissions is currently a topic of extensive debate. Scientific reports have argued that, at least in the short-run, agriculture should not be included in such a trading system (WBAE & WBW 2016). Some of the main reasons include the heterogeneity of emissions, high administrative costs and the negative effects on domestic and international competitiveness if a well-designed carbon border adjustment for agricultural and food products is not implemented. The complexity of carbon border adjustment and potential conflicts with trading partners further complicate the issue.

Whether or not a first-best option, an ETS for emissions from agriculture and agricultural peatlands offers advantages over the above-mentioned approaches. From an administrative point of view, an ETS could be introduced at the EU level, as similar systems already exist for other sectors. Moreover, it would avoid the transaction costs and uncertainties associated with negotiating multiple legal instruments at different stages. Another prominent advantage is that it directly engages private sector actors into emissions reduction efforts. It also establishes a predictable reduction pathway. Starting with a defined cap, the number of allowances available is reduced on an annual basis towards a pre-negotiated target. This makes the annual reduction pathway foreseeable for actors in the agricultural and food sectors.

Furthermore, as a market-based measure, it works with price signals, allowing flexibility in finding economically suitable management solutions. Employing economic incentives, it allows for reducing political micro-management and command-and-control interventions. An ETS furthermore generates revenues from auctioning allowances, which could become an income stream for farmers on top of support by the CAP. These revenues could, for example, be reinvested into innovation in the land use sectors or used for rewarding the provision of public goods. Alternatively, the free allocation of allowances for selected emissions, such as those from agricultural peatlands, would represent a direct transfer of assets to farm enterprises.

The debate on the shape of a potential ETS is still in its early stages. An informed opinion about the desired policy approach will require further analysis. However, several considerations regarding the design of a potential ETS for emissions from agriculture and agricultural peatlands have been outlined (Trinomics B.V. 2023), allowing for preliminary deliberations regarding the benefits and trade-offs of different approaches with such a system.

To be effective, an ETS should cover the most important sources of emissions related to the agricultural sector. This means covering methane emissions from livestock (from enteric fermentation and manure management, Chapter 4.4.4), nitrous oxide emissions from agricultural soils (with nitrogen surplus as a good proxy, Chapter 4.5.1) and emissions from agricultural peatlands (Chapter 4.6.2).[67] Another key question is who should be covered by an emissions trading obligation. The main options discussed are farmers themselves, upstream actors (e.g., input suppliers like fertiliser and feed producers) and downstream actors (e.g., large slaughterhouses, dairies, food processors, wholesalers and retailers). Each option presents challenges and advantages. The upstream model appears to be the least promising option, as inputs into the agricultural system do not closely correlate with agricultural emissions. Furthermore, this model would not cover emissions from agricultural peatlands.

Implementing an emissions trading obligation at the farm level presents challenges related to administrative management and possible transaction costs, especially in view of the large numbers of farms in the EU. This is the case despite the possibility of simplifying the entry-level administrative requirements for participation. For example, emissions could be estimated by activity levels, such as the number of dairy cows, multiplied by standard emissions factors and adjusted for the implementation of technical mitigation measures (e.g., feed additives, enhanced-efficiency fertilisers and management practices). The Carbon Removals and Carbon Farming (CRCF) Regulation (2022/0394(COD)) (see below), will lead to the establishment of certification methods for emissions reductions from agricultural activities.[68] Such certificates could help test voluntary market-based approaches for incentivising emissions reductions in agriculture before any potential ETS becomes operational. It could also help test the robustness and administrative feasibility of different farm-level Measurement, Reporting and Verification (MRV) systems.

Implementing a pricing mechanism at the farm level also comes with advantages. Emissions occur at the farm level. On-site implementation could empower farmers to develop tailored solutions, allowing them to directly benefit from adopting mitigation technologies and production practices. A threshold could be established to exclude farms with limited administrative capacity and minimal greenhouse gas emissions from coverage under an ETS. Moreover, most EU farms are already integrated into the application, payment and control systems of the CAP. This infrastructure could potentially be streamlined and extended to include the greenhouse gas account of farms, for example through a Common Agricultural Data Space (Chapter 4.5.3). Farmers could also be compensated for the administrative costs associated with participating in the ETS, potentially through mechanisms such as the CAP.

The option of a downstream model puts the emissions trading obligation on downstream actors in the value chain. This option is aligned with recent policy developments, which require greater transparency from companies on their sustainability performance. Examples include the recently updated rules under the Corporate Sustainability Reporting Directive ((EU) 2022/2464) and the Corporate Sustainability Due Diligence Directive ((EU) 2024/1760). These legislative acts oblige certain companies to report on their Scope 3 emissions, which also covers agricultural supply chains.[69] While the downstream option would involve fewer actors and could increase political acceptability, this option would still require tracing back emissions to the single farm if changes in management practices at the farm level are to be incentivised. Unless such a system addresses the risk of farmers facing multiple, incoherent reporting schemes or becoming overly dependent on a single downstream actor, it may place them at a disadvantage compared to farm-level implementation.

When evaluating the option of any carbon pricing model, farmers' international competitiveness also needs to be considered. The introduction of a Carbon

67 Including the emissions from fuel use in agriculture could also be considered, although these emissions might eventually also be covered by the recently established ETS II (Directive (EU) 2023/959).

68 Currently, soil emissions reductions, including from agricultural peatlands, are covered by the regulation. By 2026 the European Commission will need to consider whether to also include emissions reductions from livestock activities.

69 Scope 3 emissions refer to indirect emissions associated with a company's value chains. For a food sector business this will include emissions from the production of agricultural products supplied by farms. Scope 1 emissions refer to a company's direct emissions, and Scope 2 emissions are indirect emissions related to a company's energy use.

Border Adjustment Mechanism (CBAM) for agricultural products would be an option to manage the risk of leakage through imports. To make such a system practical and politically feasible it would need to focus on the main greenhouse gas-intensive, bulk-traded livestock products (i.e., beef, milk powder and butter). It should exclude processed products with low input shares of these products. Such a system would require further assessment from the perspective of the EU's trading partners. At the same time, the EU imports most of its animal products from a relatively small set of countries, increasing the feasibility of finding a common solution.

While a well-designed ETS can be the cornerstone of EU climate policy for the land use sectors, complementary measures will be needed to effectively reduce agricultural emissions. This includes food and health policies to enable healthy and plant-rich diets (Chapters 4.3 and 5.3) and the CAP to remunerate climate-friendly practices (Chapter 5.2).

Furthermore, an agricultural ETS should not hinder but rather support other sustainability objectives that are affected by agriculture. For this purpose, an ETS needs to be embedded within a wider policy mix to mitigate sustainability trade-offs and support the achievement of other societal objectives, such as enhancing social cohesion, protecting biodiversity, improving animal welfare and ensuring access to healthy and sustainable diets. Advisory services, innovation and training play an important role in enabling farmers to participate in climate policy measures.

The use of design tools internal to an ETS, such as free allowances, could also be considered for the purpose of managing trade-offs. For example, to mitigate the risk that an ETS undermines low-intensity, pasture-based livestock systems, which deliver multiple sustainability co-benefits (Chapter 4.4), an ETS could grant free allowances to these systems.[70] As mentioned above, such internal design strategies could be accompanied by supportive measures outside the trading system, such as by providing payments for the biodiversity benefits of certain grazing systems through the CAP. The degree to which sustainability dimensions beyond climate should be included into the design of an ETS, or whether those should only be supported by accompanying policies will be subject to negotiation.

Further perspectives on climate policy and the functioning of an on-farm trading system are discussed in Chapter 4 for the main sources of agricultural emissions, namely from livestock (Chapter 4.4.4), agricultural soils (Chapters 4.5.3) and agricultural peatlands (Chapter 4.6.4).

D) Incentives for carbon removals in the land use sectors

Carbon removals are indispensable for achieving climate neutrality by counterbalancing residual emissions. In the longer-term, they are necessary to help achieve net-negative emissions by withdrawing CO_2 from the atmosphere. To date, nearly all removals result from land management, mainly from forest management and afforestation (Smith et al. 2024). As described above (Chapter 4.7), the forest sink has been declining in recent years, a trend that is expected to continue without additional targeted measures. The EU is currently not on track to meet its net removal target of 310 $MtCO_2eq$ for 2030 (EEA 2023a).

The EU policy framework on carbon removals is still at an early stage of development. Deliberations on a long-term vision for the role of carbon removals have only recently started, and detailed approaches for incentivising removals are yet to be devised (European Commission 2021e). The CRCF Regulation, recently agreed by EU legislators, is a first step.[71] It establishes a framework for the development of certification methods for permanent carbon removals,

70 In the context of carbon border adjustment, equivalent preferences would have to be granted to imported products from similar production systems.

71 See also the Net Zero Industry Act (Regulation (EU) 2024/1735) which sets the target to reach an annual injection capacity of at least 50 $MtCO_2$ in the EU by 2030, which could be used for removals from technological options. See also the European Commission's Industrial Carbon Management Strategy (COM(2024) 62 final) focused on industrial carbon removals.

carbon farming and carbon storage in products.[72] The future uses of the resulting certified carbon removal and emissions reduction units are subject to further legislative proposals and negotiations. Currently, potential applications are limited to voluntary private sector initiatives or member state-driven programmes supported by public payments, including those potentially under the CAP.

An EU policy framework for carbon removals needs to ensure removals can play their increasingly important role towards 2050, while not deterring efforts on emissions reductions. For land-based removals, such a framework should create income opportunities for farmers and forest owners without running the risk of compensating emissions with non-permanent removals, which have a high risk of reversibility (Meyer-Ohlendorf et al. 2023). Moreover, certification methods need to credibly operationalise the CRCF Regulation's requirement that carbon farming delivers biodiversity co-benefits (e.g., Scheid et al. 2023).

Beyond the target-setting described above, other key components of a carbon removals framework that need to be considered include:

1. Governance of incentivising land-based removals
2. Managing the risk of reversibility and associated liability

1. Governance of incentivising land-based removals

The EU climate framework needs to reward farmers and forest owners for land management strategies that generate carbon removals and storage. The activities with greatest potential include afforestation, decreasing harvest in certain types of forests, and planting woody structures on agricultural land, such as hedges, agroforestry and short rotation coppices. As outlined above, in our scenario such woody structures provide an important contribution to carbon removals, while they can also contribute positively to biodiversity (Chapters 4.2 and 4.5). In addition, the use of biomass for materials needs to be made more attractive compared to energy use. The way biomass is harvested, processed and used determines the effectiveness of carbon removals (Chapters 4.2 and 4.7).

Support for land-based removals can rely on a complementary set of funding mechanisms. Such mechanisms include, among others, public funding (both national and EU), voluntary carbon markets (Chapters 4.2.4, 4.6.4 and 4.7.4), and different forms of integration with a compliance carbon market, such as an ETS. Any credible incentive mechanism will have to rely on a Measurement, Reporting and Verification (MRV) system that is accessible for users, both in cost and usability, and reliable in terms of results.

An important governance decision is to determine the appropriate relationship between carbon removals and emissions trading. A report commissioned by the European Commission develops three different options for integrating removals into an ETS: 1) direct integration, 2) indirect integration, and 3) no integration (Trinomics B.V. 2023). The direct and the indirect integration options open the way to compensating emissions by removals. In the "no integration" option, carbon removals are not included into an ETS compliance market, avoiding any direct compensation. In such a case, removals can still be incentivised through the ETS by allocating a portion of the revenues from allowance trading. This could still create income opportunities for farmers and forest owners without recourse to additional public funding.

From today's perspective, the "no integration" option appears to be the most effective approach. Carbon removals are indispensable for achieving climate neutrality by counterbalancing residual emissions. In the coming years, when removals are not yet needed for compensating hard-to-abate residual emissions, EU policies would need

72 The CRCF Regulation (2022/0394(COD)) identifies three categories of activities that can be subject to certification: 1) Permanent carbon removals, referring to a practice or process that stores carbon for several centuries; 2) Carbon farming, referring to the capture and temporary storage, for at least five years, of carbon into biogenic carbon pools or the reduction of soil emissions. The option of including emissions reduction from livestock will also be considered by 2026; 3) Carbon storage in products, referring to a practice or process that stores carbon for at least 35 years in long-lasting products.

to focus on creating income opportunities through land-based removals. This should be done without compromising the ambition of emissions reduction efforts. Furthermore, alternative funding options for removals should be considered outside the land use sectors, rather than depending solely on integration into an ETS.

This assessment may evolve as residual emissions, which are either difficult to mitigate or can only be reduced at substantial cost, start to predominate. Most of these emissions will likely come from agriculture. In such case, it is conceivable that the more stable land-based removals may be employed as a compensation. The feasibility of an eventual integration of land-based removals into a potential ETS for agriculture and agricultural peatlands therefore deserves further examination. A condition for such integration would be the establishment of a European authority to manage the potentials and challenges related to removals (Edenhofer et al. 2023). Acting as an intermediary between the supply and demand sides, this authority would procure carbon removals and convert them into purchasable carbon removal credits, while managing the different risks involved in such an exchange.

In the coming years, the CRCF framework could serve as a foundation for testing the robustness and administrative feasibility of using certificates. This could help build trust and test voluntary market-based approaches for incentivising climate change mitigation measures in the land use sectors. This applies both to removals in the agricultural and forestry sectors and for emissions reductions from carbon farming. Incentives could be provided through public funding mechanisms, including through payments for public goods and tenders. Voluntary carbon markets may also contribute. European legislators have approved several recent policy initiatives to help govern this process.[73]

73 For example, the Directive on Empowering Consumers for the Green Transition (Directive (EU) 2024/825) and the Green Claims Directive (2023/0085(COD)), which is still under negotiation, aim to ensure that environmental claims made on consumer products, including those related to mitigating climate change, do not result in greenwashing, and are credible and well-substantiated.

2. Managing the risk of reversibility and associated liability

EU climate policy needs to address the uncertainties related to the non-permanence of land-based removals. Compared to technological removals, carbon sequestered through land-based options is at greater risk of release into the atmosphere due to natural disturbances, such as droughts, fire and disease, or changes in land management (Meyer-Ohlendorf 2023). While elevated reversibility risk is a common feature of different land-based removals, the degree of risk varies according to removal option. For example, afforestation and agroforestry are more robust than sequestration in arable soils.

Several governance options have been proposed for managing the risk of reversibility in climate governance. These revolve around different ways of converting the value of removal options based on their reversibility risk. The CRCF Regulation, for example, sets a time limitation to the validity of different types of removal units. Other options include insurance schemes, discounting rates or restricting the eligibility of removals (Trinomics B.V. 2023, Edenhofer et al. 2023, Bellona 2022).

Finally, the degree of stringency in governing the risk of reversibility is related to how the removal is incentivised. The more direct the compensation of emissions by removals, for example in the context of a compliance market, the more meticulous the risk governance needs to be.

5.2 A Common Agricultural Policy for public goods

The Common Agricultural Policy (CAP) is the main European funding mechanism for the agricultural sector. The CAP represents over 30% of the total EU budget (European Commission 2024c). In the current funding period 2023–2027, the planned total CAP expenditure amounts to 307 billion euro in current prices, of which 264 billion euro will come from the EU budget and 43 billion euro from national budgets (European Parliament 2023b).[74]

The CAP budget is divided between two funds, often referred to as its two "pillars":

- The European Agricultural Guarantee Fund (EAGF) – the first pillar – provides direct income support for farmers and funds market measures. It has a budget of 198 billion euro in the current funding period. This is about 75% of the total CAP budget. About half of this money is paid to EU farmers as "basic income support for sustainability", a flat-rate, annual payment per hectare. Some 12% of the first-pillar CAP budget is paid as "coupled income support". A further 24% of the first-pillar CAP budget is allocated to so-called "eco-schemes", which were introduced in 2023 as part of the new "green architecture" of the CAP. Eco-schemes are measure-specific payments that support farmers who voluntarily implement one-year farming practices that contribute to the EU's environmental and climate goals. The remainder of the first-pillar budget is used to support young farmers, small- and medium-sized farmers and specific agricultural sectors. Almost 100% of the EAGF expenditure is financed by the EU.
- The European Agricultural Fund for Rural Development (EAFRD) – the second pillar – finances rural development and comprises a variety of interventions. In the current funding period, the second pillar has a budget of almost 66 billion euro – about 25% of the total CAP budget. EU countries implement EAFRD funding through Rural Development Programmes, which are co-financed from national budgets with a total of 43 billion euro. National co-financing rates vary between 20% and 85%, depending on the measure and region. At least 35% of the funding for each Rural Development Programme must be dedicated to measures which contribute to environmental and climate protection (European Commission 2024c).

74 The following budget information relates to the funding period 2023–2027 and the EU financial contribution without national co-financing.

The CAP has been criticised for many years for not contributing sufficiently to achieving environmental and socio-economic goals (WBAE 2018, Pe'er et al. 2019, Lillemets et al. 2022). For the current funding period 2023–2027, the ambition was to provide a "fairer, greener, more animal friendly and flexible CAP" in line with the EU Green Deal and its Farm to Fork and Biodiversity strategies (European Commission 2021j). The latest CAP reform introduced a new "green architecture" and allocated more funds to environmental and climate actions (Röder et al. 2024). Another cornerstone of the CAP 2023–2027 is the "new delivery model" based on national CAP Strategic Plans (Regulation (EU) 2021/2115). This new delivery model gives member states considerable flexibility to adjust CAP instruments and allocate CAP funds according to their respective needs.

In principle, the current CAP allows member states to use all available funds to remunerate the provision of public goods by agriculture. However, member states also have many degrees of freedom not to do so. There are too few guardrails to enforce or credibly encourage the targeted spending of CAP money (Grethe & Chemnitz 2023, Röder et al. 2024). As a result, the CAP budget is not sufficiently targeted at providing public goods, also in the current funding period (Baldock & Bradley 2023, OECD 2023, Cuadros-Casanova et al. 2023, Guyomard et al. 2023, Midler et al. 2023).

The large share of the CAP budget which is not targeted at the provision of public goods endangers societal acceptance as well as a successful maintenance of the CAP budget in the Multiannual Financial Framework (MFF) negotiations. Representing nearly a third of the multiannual financial framework, the CAP will be exposed to the constraints bearing on the EU budget, such as additional expenses for international security policies and a potential EU enlargement including Ukraine. Maintaining the CAP budget is likely only if reforms are implemented to ensure more cost-efficient use of funds. However, any strategy based on "budget against reforms" (Heinemann 2017: 13) threatens to fail because the decision on budgetary envelopes in the multiannual financial framework will be taken earlier than on the CAP reform itself. The key to a CAP reform that effectively

Infobox 9: What are public goods?

The call to align all CAP interventions with the principle of "public money for public goods" is raised in every CAP reform debate. This requires an understanding of what public goods are and how they can be distinguished from private goods.

The term "public goods" applies to a range of goods and services of societal interest that are usually undersupplied by the market, or by the interplay of supply and demand (European Commission et al. 2010, OECD 2013, Westhoek et al. 2013). In economic theory, a public good is defined by two characteristics. First, a public good is non-rivalrous. That means that if a good is consumed by one person, this does not diminish the benefit available to others. Second, a public good is non-excludable. This means that if the good is available to one person, others cannot be excluded from enjoying its benefits.

Markets typically do not supply public goods to a sufficient extent. On the demand side, there is no incentive for individuals to pay for a public good. Therefore, on the supply side, there is no incentive to provide it. If society wants more public goods to be provided, their supply may be supported by public intervention. Incentives to provide public goods can be set, for example, through regulatory standards or payments.

Environmental goods such as clean water and air, rich biodiversity and climate protection are standard examples of public goods. Animal welfare can also be included, if demanded by society (Chapter 3.4). Safeguarding agricultural livelihoods to ensure social cohesion in rural areas might likewise be a public good objective. This applies in particular to lower-income regions where agriculture accounts for a high proportion of employment and where alternative job opportunities are scarce. These examples show that the definition of what constitutes a public good needs to take into account the specific contexts and challenges of different member states and regions. However, for the use of CAP funds to be justified, a public good will need to be sufficiently well-defined with operationalised criteria so that a clear relationship between payment and impact can be established. In this sense, while in principle, "food security" is a public good, the distinct contribution of CAP payments to food security in the EU is hard to determine (Cooper et al. 2009). Food security in the EU is not endangered by insufficient food supply (Chapter 3.3). Solutions for ensuring access to food for specific population groups lie predominantly in the realm of social and food policies, not agricultural policy.

delivers on public goods will therefore be the European Commission's proposal for the multiannual financial framework, expected in 2025, which would have to provide a conducive framework for an ambitious design of the future CAP (Régnier et al. 2023).

The CAP does not need to be reinvented. The current CAP architecture, including the new delivery model, provides an ample basis for using available funds to pay farmers for public goods. The challenge for the next funding period is to set the right incentives for member states to put together ambitious, attractive and cost-efficient packages of measures in their strategic plans. This is urgently needed, because both the EU and member states are facing mounting pressures to deliver on legally binding sustainability objectives related to the land use sectors. In the context of fiscal scarcity, reaching these objectives will require an efficient use of CAP money. The funds required for biodiverse agricultural landscapes in the EU alone are estimated to amount to between 9 and 20 billion euro per year (Annex Chapter 6). This corresponds to around one-third of the current annual EU CAP budget.

To improve the environmental and socio-economic impact of the CAP, the following steps can be taken.

A) Phase out basic and coupled income support
B) Redirect CAP funds towards environmental and socio-economic impact
C) A simpler and more flexible CAP

A) Phase out basic and coupled income support

A large part of the CAP budget is spent on basic income support and coupled income support. They constitute flat-rate, annual payments for all eligible hectares.[75] Basic and coupled income support are considered inefficient both in achieving environmental objectives and in providing income support where it is actually needed (WBAE 2018, ECA 2022, Pe'er et al. 2020, Chatellier & Guyomard 2023). Nonetheless, all farmers in the EU have access to basic income support.[76] In the current CAP period, all EU countries except the Netherlands grant coupled income support to certain products – even though coupled payments incentivise production and thereby distort the market.

Basic and coupled income support are fully financed from the EU budget without national co-financing. This makes maximising budget allocation to basic and coupled income support a popular choice, crowding out other instruments that could provide greater public benefit (Matthews 2018). For the funding period 2023–2027, about 97 billion euro are allocated to basic income support, and about 23 billion euro are allocated to coupled income support. Together, they account for around 45% of the total CAP expenditure (European Parliament 2023b).

The inaccuracy and inefficiency of basic and coupled income support provides a strong rationale for their phase-out during the next CAP period starting in 2028 (Grethe & Chemnitz 2023). The money currently spent on basic and coupled income support is urgently needed to tackle the environmental and socio-economic challenges that EU agriculture is facing (Pe'er et al. 2019, Scown et al. 2020). However, the phase-out of basic and coupled income support must be gradual so that farmers, markets and administrations can adapt.

The best option is a transparent plan for a phase-out of basic and coupled income support with a budget allocation that shrinks from year to year. This can be ensured, for example, by requiring member states to reallocate an increasing share of the budget from basic and coupled income support to eco-schemes and second-pillar measures.

Introducing national co-financing of first-pillar CAP payments could be another entry point to phasing out basic and coupled income support (Heinemann 2017, Hofreither 2013, Matthews 2018). National co-financing would require member states to take greater ownership of basic and coupled income support and to justify them in the national budget debate.

From a member state perspective, national co-financing of first-pillar CAP payments would be beneficial for net payers to the first pillar – but would be costly for net recipients.[77] In order to gain acceptance for the introduction of national co-financing among member states that are net recipients of the first pillar, Matthews (2018) suggests 1) to impose different national co-financing rates depending on the gross domestic product per capita, and 2) to trade off higher second-pillar allocations for lower first-pillar allocations. Along the same lines, Hofreither (2013) proposes progressive co-financing rates for direct payments. The idea is that national co-financing rates increase with increasing payment levels. Low payment levels could remain exempted from national co-financing.

75 Coupled income support can also be paid per animal.
76 For information on eligibility criteria for direct payments of the CAP 2023–2027 see European Commission (2024f).

77 Net payers to the CAP first pillar are member states whose share of CAP first pillar receipts is lower than their contribution to the EU Gross National Income, which determines the contribution to the EU budget.

B) Redirect CAP funds towards environmental and socio-economic impact

The phasing out of basic and coupled income support is an important prerequisite for a cost-effective and coherent CAP that remunerates farmers for public goods. The released budgetary resources would allow farmers to be paid for their contribution to sustainability targets. However, a reallocation of funds from basic and coupled income support to eco-schemes, agri-environmental and climate measures and other second-pillar interventions is not enough. In addition, incentives are needed to encourage member states to launch ambitious and targeted interventions to address environmental and socio-economic challenges.

Crucial to this is the approval process of CAP strategic plans by the European Commission. It gives the Commission the opportunity to check whether the designed CAP interventions in the strategic plans are aligned with the overarching CAP objectives. If necessary, adjustments to the strategic plans can be enforced or incentivised.[78]

To provide both member states and the Commission with a solid basis for the ex-ante planning and ex-post evaluation of CAP interventions, the indicator system in the Performance Monitoring and Evaluation Framework needs to be refined and complemented. At present, the performance of individual CAP interventions, and hence national strategic plans, is assessed primarily on the basis of result indicators and output indicators (Hart 2024). A total of 44 result indicators are used to link CAP interventions to overarching CAP objectives (e.g., "protecting water quality" and "generational renewal"). Member states set targets such as the number of farms, agricultural land or animals to be covered by a CAP intervention at a given payment rate and calculate the expected expenditure. Annually, the Commission checks if member states' expenditure is matched by the realised outputs.

78 In principle, the European Commission is authorised to reject CAP strategic plans. However, this is very unlikely to happen, as both the Commission and the member states have a great interest in ensuring that the available CAP funds can be spent in full in good time at the start of a new funding period (Röder et al. 2024).

However, counting hectares, heads and expenditures is not sufficient to get an adequate picture of the effectiveness of individual CAP interventions and national strategic plans in addressing environmental or socio-economic challenges (Röder et al. 2024, Münch et al. 2023, Pe'er et al. 2019). To make the causality between output and impact the benchmark for evaluation, Röder et al. (2024) recommend weighing output indicators with their respective environmental or socio-economic impact.[79] The results of the iMAP project (European Commission & JRC 2023) can be a starting point for this purpose.

Based on such weighted output indicators, minimum targets could be defined that must be achieved for strategic plans to be approved by the Commission. Weighted output indicators could also be used to reward ambitious CAP interventions with low national co-financing rates to reflect European value added (Matthews 2018).

The phasing out of basic and coupled income support and the expansion of the CAP indicator system require only minor adjustments to the CAP architecture but would have a significant impact on its functioning and performance.

C) A simpler and more flexible CAP

Merge CAP funds. If the same co-financing and evaluation criteria are applied to all CAP interventions, there is no longer a need to divide the budget into two pillars. The CAP would be financed from a single fund to reflect its new focus on public goods. This would also eliminate the administrative procedures

79 The discussion about assessing the impact of measures at member state level is to be distinguished from the discussion on result-based payments at farm level. We are cautious about the potential of result-based payments instead of action-based payments under the CAP. This would mean, for example, that farmers would only be paid for a measurable increase in soil organic carbon content or for the presence of target species on their land. In many cases this would not be justified because the effectiveness of agri-environmental measures often depends on conditions beyond the farmer's control such as weather, climate change or the management of neighbouring land (Hart 2024). Careful case-by-case assessment is therefore required when introducing result-based payments.

for reallocating funds between the pillars and, in some member states, simplify the coordination of CAP interventions between national and regional agricultural administrations. In addition, replacing the existing one-year rule for the repayment of uncalled funds to the EU with a multi-year rule would increase budgetary flexibility and enhance the piloting of innovative funding instruments.

More flexibility should also be given in the implementation of CAP measures on farms. For example, multi-year implementation of agri-environmental measures often brings greater benefits, while single-year measures also have their value and justification. Today, payments for agri-environmental and climate measures under the second CAP pillar are often only paid out if farmers adhere bindingly to defined farming practices over a fixed period. Many farmers are put off by the risk of having to pay back the money they have already received if they want to terminate the measure early. Progressive payment rates that increase with each year of adherence are one way of making it attractive to maintain measures without unduly restricting the entrepreneurial freedom of farmers. Every year, farmers can make new decisions and terminate measures if the opportunity costs become too high.

Collective planning, implementation and management of agri-environmental and climate measures can reduce the burden on individual farms substantially (Chapter 4.5.3). In the Netherlands, for example, regional cooperatives collectively provide certain environmental services previously agreed on with the agricultural administration. Which individual farms provide this service in which years is the subject of individual private-law agreements between the farmers and the cooperatives and can change within a funding period (BoerenNatuur 2023, Dik et al. 2023).

Substitute conditionality. An important question is what minimum standards can be placed on EU farmers and how compliance can be ensured. In the CAP funding period 2023–2027, the so-called enhanced conditionality replaced the previous system of cross compliance. Conditionality comprises two elements (European Commission 2024e). All EU farmers, whether they receive CAP support or not, have to comply with statutory management requirements. In addition, farmers receiving CAP support must comply with EU standards on Good Agricultural and Environmental Conditions (GAECs) and in future with social conditionality (but see Lyngs 2024). As the vast majority of EU farmers receive at least basic income support, the GAECs de facto apply to almost all EU agricultural land. GAECs are thus closely linked to the logic of basic and coupled income support, and their role will have to be reviewed in a public goods-oriented CAP.

The challenge is to replace GAECs while maintaining baseline environmental protection, while at the same time not introducing undue additional standards on the sector without remuneration. This includes negotiating which standards can be imposed without financial compensation, and which should be included in funding programmes. It is important (and in the direct interest of farmers) that there are minimum standards to which all farmers must adhere, that these minimum standards apply reliably – regardless of the political climate – and that compliance is monitored. Many of the changes made to GAECs since the beginning of 2024, such as the plan to completely exempt farms with less than 10 hectares from controls related to compliance with GAECs (European Commission 2024k), affect the environmental performance of the CAP. This decision threatens to worsen the negotiating position of the agricultural sector in the upcoming multiannual financial framework negotiations on the CAP budget for 2028–2035 (Lakner & Röder 2024).

Providing public goods must be profitable. Farmers should be able to earn money by providing public goods. The CAP must create the right conditions for this. Payment rates should target an effective level of participation and must therefore be financially attractive for participants. The question of whether, for example, the payments for eco-schemes and agri-environmental and climate measures can have an explicit income component, or whether they should compensate only for income foregone and costs incurred, is the subject of controversial debate (Röder 2021). In practice, the responsible authorities already have a wide range of options for making payment rates attractive. Depending on whose costs form the basis for calculation, the provision of public goods will always be both overcompensated for some farmers and undercompensated for others.

One major challenge is to adjust payment rates to different levels of opportunity costs. In practice, this would mean that farmers on sites with high yield potential would receive higher payments than farmers on sites with low yield potential. This is often perceived as unfair, even though higher payments in high-income regions compensate only for costs incurred and thus do not raise incomes (Röder 2021). Differentiating payments is the prerequisite for implementing voluntary environmental measures in high-input regions where they often generate particularly high benefits. Differentiated payments therefore increase the efficiency of public expenditures.

Conclusion. Essentially, the CAP architecture can remain largely as it is if the right incentives are put in place to use its flexibilities in favour of targeted interventions. This principle applies not only to the CAP after 2027, but also to the current funding period 2023–2027. The current CAP rules already allow funds to be used more efficiently. National strategic plans can be reviewed and revised annually. For example, eco-schemes can be adapted, unsuitable ones cancelled, and new ones introduced. Additional funds can be shifted from basic and coupled income support to eco-schemes or second-pillar interventions. Experimenting with innovative measures within the current framework, such as pilot projects, can be implemented flexibly and will be critical for paving the way for a cost-efficient and coherent CAP that delivers on public goods.

5.3 EU Legislative framework to promote sustainable food systems

In 2020, the European Commission announced its intention to publish a proposal for a legislative framework to facilitate the transition towards a more sustainable EU food system (European Commission 2020a). Although foreseen for 2023, the proposal was delayed and was later absent from the European Commission's 2024 work programme. Preparatory work for the framework by the Joint Research Centre (Bock et al. 2022) as well as the inception impact assessment (European Commission 2021g), suggest a comprehensive scope for the initiative, with a prominent place for food consumption and food environments.

As described in Chapter 4.3, a gradual shift in food consumption patterns towards healthier, more plant-rich diets can contribute to improving the health of the European population and reducing healthcare costs associated with diet-related diseases, which are highly prevalent (Chapter 3.3). A shift in food consumption patterns is essential for public health reasons, but is also needed to support the achievement of other sustainability objectives, such as the reduction in greenhouse gas emissions and biodiversity protection. Our scenario shows that without more plant-rich diets and a reduction in food waste, environmental sustainability gains inside the EU would relocate production to other parts of the world, increasing greenhouse gas emissions and pressure on land resources in third countries (Chapter 4.1).

Integrated food policies that offer coherent solutions across health, social, economic, environmental, climate and agricultural policy domains are yet to be developed at both the EU and national levels (EEA 2023e, European Commission & Group of Chief Scientific Advisors 2023). In addition, policies to enable more sustainable consumption remain underexplored and have, so far, excessively relied on the provision of information to consumers, which has only limited impact. Food policies are needed that create fair food environments making healthy and sustainable diets more available, affordable and attractive for consumers. Food environments exert significant influence on food choices, for example through the meals available in canteens and schools, the relative affordability of different products and how food is labelled and promoted in retail settings (Chapter 4.3).

Putting forward a legislative framework that helps negotiate and establish the building blocks for a coherent policy approach for a more sustainable EU food system therefore continues to be a central task for this legislative period. Such a framework, which would support policy efforts at both the EU and national levels, would need to contain at least the following two elements (Chapter 4.3.4):

- **Objectives and principles for more sustainable EU food systems**. The establishment of common objectives and principles can support greater predictability about the future evolution of the food system for actors across the supply chain. They can also provide a guiding framework for policymakers for the gradual adaptation of existing policies and the development of new policies, thereby facilitating the introduction of design features that reduce trade-offs between different sustainability objectives, while supporting synergies.
  For example, well-defined sustainability objectives can help set the parameters and boundary conditions for policies such as minimum requirements for public food procurement and sustainability labelling for food products (Chapter 4.3) or a potential emissions trading system for agriculture-related greenhouse gas emissions (Chapter 5.1).
- **A mechanism to set off a process for the development of national food strategies and action plans**. Very few countries in the EU have so far established national food strategies, and none have introduced a comprehensive policy mix of actions for the creation of fair food environments. Putting a mechanism in place to embark on a process of designing and implementing such strategies and plans will be critical for enabling consumers and food sector business to realise a gradual shift in food consumption patterns in support of sustainability objectives. The development of national food strategies will allow actions to be tailored to national and local food cultures, socio-economic conditions and other more regional features of food environments and food supply chains.
  The establishment of an EU platform for facilitating exchange on the development of such national strategies and plans between member states, the European Commission and other relevant actors in the food system about processes, core objectives, key elements, instruments and best practices could add important value. The set-up of such a platform can build on the experiences of the EU Platform on Food Losses and Food Waste, which has been active since 2016. Such a platform could also be established even before a legislative framework comes in place.

A legislative framework could contribute to, among others, the following benefits:

- By defining common objectives, the framework could signal a long-term direction for the food system. This could contribute to innovations and new business models for food sector businesses in the EU, improve the trust of investors, and allow a better targeting of sustainable finance instruments in the food sector.
- By advancing policy coherence and closing regulatory gaps, it can contribute to a level playing field across the EU. For example, it could help harmonise legislation on sustainability labelling or provisions regarding marketing and advertising (Chapter 4.3.4).
- By initiating the development and implementation of national food strategies, it would support the development of more integrated food polices. National food policies aimed at creating fair food environments need to consider the social policies required to tackle food poverty and contribute to healthy and sustainable diets being affordable for all. This is even more important if carbon pricing will have impacts on the prices of certain food products (Chapter 4.3.4).

5.4 Action plan for the efficient use of biomass in the bioeconomy

Biomass plays a central role in the economy, supplying food and feed, energy, wood for construction, fibres for paper and clothing, and the carbon feedstock for bio-based products, such as plastics and a variety of chemicals. It also delivers carbon storage. As we show in our scenario, if used efficiently and produced sustainably, biomass can play an important role in the transition of the EU economy towards climate neutrality, while simultaneously contributing to other societal objectives. However, the EU's current policy framework does not yet provide coherent and long-term incentives to stimulate a bioeconomy based on an efficient use of biomass. The review of the Bioeconomy Strategy (European Commission 2018a), planned for 2025, provides an opportunity to rectify this.

The use of biomass for bioenergy and materials in the EU has increased by roughly 16% between 2010 and 2020,[80] bioenergy being accountable for 80% of this growth (JRC 2022). In our scenario, which is based on an efficient allocation of biomass, we project a further 20% increase in demand for non-food, non-feed biomass uses between 2020 and 2045. This results from an increased demand for material use[81] and a somewhat reduced demand for bioenergy (Chapter 4.2). Other projections estimate increases in biomass demand for bioenergy and bio-based materials to range between 50% and 150% by 2050 compared to today (EEA 2023d). Most biomass (including for food and feed) in the EU is supplied through land-based ecosystems. Agriculture, including food, residues and grazed biomass, accounted for almost 70% and forestry for 27% of total biomass volume by dry weight in the EU in 2017 (JRC 2023).

Producing biomass requires land. This opens new economic opportunities for agriculture and forestry. At the same time, it exacerbates trade-offs between different land use functions (Chapter 4.1). Climate change is an important accelerator of these pressures. Many contributions to climate change mitigation, such as substituting fossil feedstocks, deploying renewable energies, and enhancing carbon removals rely on increased use of both land and biomass. At the same time, the effects of climate change, such as droughts and flooding, are impairing the performance of the land use sectors to deliver the needed functions (Chatham House 2023).

Incentives related to the production, extraction and use of land-based biomass are governed by a wide range of EU policies, including on energy, climate, environmental and agriculture. Taken together, the incentives provided by these policies are not coherent with an optimal use of biomass for a balanced contribution to sustainability objectives. Mixed policy signals and unaligned incentives impair planning security which would be necessary to stimulate future-oriented investments in the bioeconomy.

One example of the contradictions in the current policy framework is the policy incentives for bioenergy, which are not in line with the most climate- and land-efficient uses of biomass or with increasing carbon removals. In light of the multiple sustainability trade-offs related to the production of bioenergy and biofuels, the Renewable Energy Directive ((EU) 2018/2001)) still lacks mechanisms to effectively target the use of bioenergy to those sectors with limited other options (ESABCC 2024). This notwithstanding a recent revision of the directive (RED III)[82] that strengthens sustainability safeguards, such as the introduction of a cascading principle for the sustainable use of woody biomass and a more differentiated approach towards biofuels in transportation.

Despite some steps in the right direction, the directive continues to incentivise the deployment of bioenergy. This especially in conjunction with the zero-rating rule under the EU Emissions Trading System (EU-ETS), which counts burning biomass as carbon neutral without distinguishing between different forms of biomass (Chapter 4.2).[83] This situation stands in tension with the carbon removals target established for the LULUCF sector by 2030.

80 Latest data available for each sector: 2020 for agriculture, 2016 for fisheries and aquaculture and 2017 for forestry.

81 The term "material use" in our scenario also includes biomass used as a feedstock in the chemical industry for producing bioplastics and other biochemicals.

82 See Directive (EU) 2023/2413.

83 Greenhouse gas emissions from zero-rated biomass in installations covered by the EU Emissions Trading System (EU-ETS) increased from 120 $MtCO_2eq$ in 2013 to 173 $MtCO_2eq$ in 2022 (European Commission 2023k). While these emissions are accounted for in the national greenhouse gas inventories at the point of harvesting trees, they are not priced when released into the atmosphere, resulting in a lack of incentive to use wood as a material rather than an energy source. In addition, under the EU-ETS the capture and storage of these biogenic greenhouse gas emissions is at present not incentivised.

The achievement of this target will in practice largely depend on the impact of climate change on forests and on the amount of wood harvested, which is likely to increase with a high bioenergy demand (Chapter 4.7).

Likewise, the current renewable fuels mandate for the transport sector under the RED III, continues to provide incentives for the use of first-generation biofuels from annual field crops, despite a cap on crop-based biofuels (ECA 2023b). This even though this is usually an inefficient way of decarbonising light vehicle road transport (Chapter 4.2).

Furthermore, as part of its REPowerEU plan,[84] the European Commission has set the aspirational target of upscaling EU biomethane production to 35 billion cubic metres (bcm) per year by 2030 (European Commission 2022d). Although not a binding target, it remains a guideline for policy and is for example promoted in the context of National Energy and Climate Plans (NECPs) (European Commission 2023d). The REPowerEU plan originally emphasised that priority should be given to the anaerobic digestion of agricultural and forestry residues and organic waste to avoid land use conflicts with food and animal feed production. Nevertheless, there is a lack of binding guidelines that classify different feedstock in terms of their land use effects. Likewise, there are at present no requirements to avoid fugitive methane emissions in biogas production. While the feasibility and desirability of the 35 bcm biomethane target relies on the ability to mobilise a sufficient supply of sustainable feedstock, to date only a fraction of the technical potential of agricultural residues and organic municipal waste can be mobilised economically (Chapter 4.5). In the absence of a sufficient supply of sustainable feedstock, the 35 bcm biomethane target risks to be delivered through an inefficient expansion in the cultivation of annual energy crops.

84 See also the recently approved EU Hydrogen and Gas Decarbonisation Package, consisting of Regulation (EU) 2024/1789 and Directive (EU) 2024/1788 on common rules for the internal markets for renewable gas, natural gas and hydrogen, which include provisions that facilitate the upscaling of biogas and biomethane.

In our scenario, we illustrate the importance of an enabling policy environment to promote an efficient use of land and a sustainable demand for food, feed and other biomass. Such a predictable and coherent policy environment is also crucial for foresight and planning security, which are key for stimulating investments into future-oriented bioeconomy value chains and for avoiding unwanted lock-ins or stranded assets.

The European Commission has committed to review its Bioeconomy Strategy from 2018 (European Commission 2018a) by the end of 2025, in order to update it in view of current challenges and to reinforce the bioeconomy's industrial dimension (European Commission 2024d). To support the development of a sustainable bioeconomy and to create synergies between different policy fields affecting biomass supply and use, this revision would need to include an Action Plan for the efficient use of biomass in the bioeconomy, including carbon removals.

An action plan for biomass would establish a set of strategic priorities for the coming months and years. These can include themes where existing evidence clearly indicates that policy adjustment is needed to reduce prevailing distortions and enhance system-wide benefits. It can also include areas where further consideration is needed about the trade-offs, benefits, and technological and economic potentials of different biomass uses. Given the cross-cutting nature of biomass, implementation of these priorities requires close integration with the process of establishing a climate governance framework for the land use sectors (Chapter 5.1) and the proposed Legislative framework to promote sustainable food systems (Chapter 4.3).

Based on our scenario we suggest the following thematic priorities for such an action plan:

- **Adopt a policy road map for stimulating long-lasting and circular uses of biomass**. Our scenario is premised on biomass being increasingly used for materials, while energy use declines. We also stress the importance of increasing carbon removals and storage. Enhancing incentives for long-lasting material uses of biomass is critical for successful climate and land use policies. Despite EU initiatives to promote long-lasting biomass uses,[85] the totality of existing EU policies does not support a move in this direction. A policy road map would set out measures to progressively adapt existing EU policies and fill policy gaps.

- **Incentivise the development of new value chains in the bioeconomy**. To grow a future-oriented bioeconomy, specific attention is required to support the establishment of new bioeconomy value chains (Chapters 4.2 and 5.5). Consistent with the previous consideration, investments for biomass utilisation would predominantly have to be steered into sectors with a long-term perspective for biomass uses, including for long-lasting products from paludiculture and forestry (Chapters 4.6 and 4.7), for biogas production based on sustainable feedstock (Chapter 4.5) and for carbon removals (Chapters 4.1 and 4.7). To help mobilise private investments in sustainable value chains, biomass uses that would provide system-wide benefits could be codified, for example, in the context of the EU Taxonomy (Regulation (EU) 2020/852). In addition, lead markets for such products could be established and differential treatment in public procurement ensured. Furthermore, actions could include the development of value chains for long-lasting wood products certified under the Carbon Removals and Carbon Farming (CRCF) Regulation (2022/0394(COD)) (Chapters 4.2, 4.6 and 4.7).
- **Promote a larger role for fast-growing trees in biomass production.** When well-integrated into the landscape, fast-growing trees, which can be harvested for lignocellulosic biomass, provide a significant potential to deliver on multiple sustainability dimensions such as local carbon sequestration, biodiversity, water protection and climate adaptation. A coordinated effort is needed to explore the barriers and opportunities for the expansion of such systems. An integrated strategy spanning multiple policy fields is required to enhance the role of these biomass production systems in a sustainable way (Chapter 4.2).
- **Evaluate the international trade dimension of EU biomass supply and demand**. Through markets for agricultural commodities, wood and wood products, energy-intensive materials as well as platform chemicals, EU biomass systems are linked to global markets. An action plan for biomass provides room to evaluate the role of local and global supply of biomass, thereby clarifying the importance of securing strategic supply chains of biomass, bio-based chemicals and other related products. In this study, we show that a scenario with a reduced global land footprint of EU food and feed consumption is possible, while also supplying the bioeconomy and certain applications of bioenergy with domestic raw materials. An action plan for biomass within a revised EU bioeconomy strategy is a good opportunity to consider what safeguards, such as for example a carbon border adjustment, might be required against carbon leakage and the offshoring of other negative environmental and social effects of EU biomass systems. This would include, for example, the depletion of land-based sinks in third countries as response to increased EU demand, beyond already existing rules in the Deforestation-free Products Regulation ((EU) 2023/1115).
- **Provide a comprehensive analysis of the current production, extraction and uses of biomass and their future potentials.** Understanding the ecological boundaries of the bioeconomy is one of the priorities of the European Commission's current Bioeconomy Strategy and its Action Plan (European Commission 2018b). In light of developments in policy, markets and ecological conditions, it continues to be important to analyse and monitor how biomass production, extraction and use can affect and contribute to different societal objectives, such as climate change mitigation and adaptation, including the creation of carbon sinks and the maintenance of soil organic matter, biodiversity protection, economic value added and food security.
This is needed, not least, to underpin ex-ante impact assessments for policy initiatives affecting biomass

85 See for example, the aspirational target to have at least 20% of carbon in chemicals and plastic products to be from sustainable non-fossil sources by 2030 (European Commission 2021e), the Energy Performance of Buildings Directive ((EU) 2024/1275) which requires a life cycle assessment of buildings also covering the embodied carbon of building materials, thereby improving the position of wood and paludiculture products as construction materials, or the CRCF Regulation which will establish certification methodologies for products storing carbon for at least 35 years, such as long-lasting wood products.

use. To help navigate the complexities involved in decision-making about an efficient deployment of biomass in the context of competing demands placed on land, such a comprehensive analysis could:

- Assess the direct and indirect impacts of EU legislation and policies on the investment and management decisions of land users, the supply of biomass, the demand and efficient use of biomass and on biomass imports and exports. This would help provide a detailed answer to how current legislation and market functioning continue to stimulate bioenergy uses of biomass, compared to materials and carbon removals and storage.
- Examine the sustainable biomass supply potential under different assumptions, including different land use scenarios for food and feed demand and the potential effects of climate change on biomass production in the EU.
- Analyse the relative advantages and disadvantages of different uses of biomass relative to alternative defossilisation options, taking into account the technological readiness of different applications and their system costs.
- Consider the possible trade-offs and benefits of different EU biomass demand and supply scenarios for land and water use, climate change mitigation and adaptation efforts and biodiversity globally.
- Project future biomass demand from existing and new uses 1) with the existing policy framework and 2) optimised regarding the analysed trade-offs and relative (dis)advantages (see previous points) in the context of a circular economy with an optimised cascading and circular use of carbon.[86]
- Identify the policy gap between projections according to existing EU legislation and the optimised projections.

86 This would, among others, include focus on the role, scope and potential of Biogenic Carbon Capture and Storage (BioCCS). This in order to guide investments into those sectors that will have to rely on biomass in the long-term and to inform policy solutions that mitigate trade-offs between the deployment of BioCCS and other land use objectives (CONCITO 2024). Also, in order to assess the efficiency of BioCCS relative to other carbon removal options, such as forest sinks. Likewise, it is important to explore the role of Sustainable Aviation Fuels (SAF) in future biomass demand. A gradually increasing share of SAF in total aviation fuels is mandated by the REFuelEU Aviation initiative (Regulation (EU) 2023/2405).

Such an action plan for biomass, apart from guiding EU policy development, could also strengthen policy processes at national levels. It could, for example, support national governments in improving coherence regarding biomass and land use while drawing-up different national plans mandated as part of EU legislation (OECD 2020). Such plans include National Energy and Climate Plans (NECPs), CAP Strategic Plans and National Restoration Plans for nature. This also applies to policy areas where national policy is prevalent, such as national forest policies or national peatland strategies. Creating a regularly updated biomass dashboard, based on the EU Biomass Flows platform by the European Commission's Joint Research Centre (JRC 2022), may further support policy making by providing detailed, timely, harmonised and accessible data. It should furthermore be considered whether a process is needed involving member states, experts and other stakeholders for building consensus about the main components of a sustainable future bioeconomy.

5.5 A European Rural Deal

Agriculture has historically responded to diverse changes, from fluctuations in the prices of production inputs and agricultural products, to new consumer demands and the emergence of technologies, as well as variability in climatic conditions. The transition of the EU economy towards climate neutrality, the need to meet other sustainability demands and the impacts of climate change will be driving further changes in agriculture and forestry in the coming decades.

As we outline in our scenario, some of the greenhouse gas intensive production systems, such as livestock production and farming on drained peatlands, will experience a significant decline. Harvest levels in some forests will also decrease. Although this will strengthen the land use sectors' contribution to societally agreed sustainability objectives, it presents a challenge for producers.

At the same time, the total demand for products and services from agriculture and forestry will increase.

Farmers, forest owners and rural entrepreneurs will play an increasingly central role in the transition to a more sustainable and climate neutral economy. For example, the growing demand for biomass from the construction sector or from industries that substitute their fossil-carbon inputs with biogenic carbon can create opportunities to cultivate fast-growing trees and paludiculture crops on agricultural land, as well as for forestry (Chapters 4.2, 4.6 and 4.7). There is significant scope for producing renewable energies, such as solar photovoltaics (PV), wind and residue-based biogas (Chapters 4.1, 4.5 and 4.6). New food demands, such as for fruits and vegetables, which offer high added value per hectare, and regional products can create new market opportunities (Chapter 4.3 and 4.5). Furthermore, the provision of public goods, such as biodiversity protection, carbon sequestration and animal welfare, can contribute to viable business models (Chapters 4.1, 4.2, 4.4 and 4.5).

Securing a reliable funding mix to transform these opportunities into tangible outcomes is critical and must be a key focus of the EU's political agenda. The upcoming negotiations for the Multiannual Financial Framework (MFF), represent a pivotal moment for addressing this need, because they will determine the size and orientation of the 2028–2034 EU budget. As this process unfolds, it is essential to engage in a well-informed debate regarding the overall costs of necessary changes in the land use sectors. This debate should address the equitable distribution of these costs, the roles of various funding sources — including public, private and public-private sources — and the responsibilities at the EU, the national and the local levels.

Among others, this debate would need to:

- Consider the role of the Common Agricultural Policy (CAP) in the wider funding landscape, in view of the important synergies a public goods-oriented policy can provide for climate adaptation and mitigation, enhancing biodiversity and supporting the readiness to adopt new production methods and technologies (Chapter 5.2).
- Examine how other funds from the current European Structural and Investment Funds[87] could contribute to the transformation needs of rural areas.
- Assess whether and to which extent the revenues from the current EU Emissions Trading System (EU-ETS) and a potential new trading system for emissions from agriculture and agricultural peatlands (Chapter 5.1) and how these revenues could be allocated to address societal needs within the land use sectors and the food system.
- Evaluate ways to mobilise funding for nature restoration and climate change adaptation, including for the introduction of natural landscape features bordering agricultural areas and for the multiple benefits that resilient forest ecosystems can provide for climate change mitigation, adaptation and biodiversity.

While considering funding needs, it is important to recognise that the economic potential of the land use sectors cannot be discussed independently from the context of rural areas in which these sectors are embedded. Much of EU's economic development is expected to be driven by the ongoing "green and digital" transitions. While these can create important opportunities, they also risk widening existing disparities between some rural and urban areas and may introduce new regional inequalities. Although improvements have been made in cohesion in the EU, certain regions, rural areas included, may be left behind unless targeted action is taken (European Commission 2024i, Bertelsmann Stiftung 2022).

Rural areas are diverse, making it crucial not to oversimplify their socio-economic conditions. However, on average and despite some progress, per capita GDP in rural areas remains substantially below that in urban areas (Eurostat 2022b). Rural areas also tend to score less favourably on a range of other socio-economic indicators, including standard of living, employment and education compared to urban areas, towns and suburbs (Chapter 3.5). Furthermore,

87 Consisting of, among others, the European Regional Development Fund and Cohesion Fund (Regulation (EU) 2021/1058), European Social Fund Plus (Regulation (EU) 2021/1057) and European Maritime and Fisheries Fund (Regulation (EU) 2021/1139).

a significant gap can be observed in access to different social services, such as schools, train stations and healthcare services (Eurofound et al. 2023). This gap tends to be larger for remote rural areas.[88] For example, disparities in population development (ageing and depopulation being more prevalent in remote rural areas), household incomes, internet speed and distance to schools are more accentuated (Perpiña et al. 2023).

To date there is insufficient confidence among rural residents that the opportunities associated with a net-zero, more environmentally sustainable European economy will manifest as tangible benefits at the level of individual entrepreneurs and rural communities. This comes at a price. Insufficient high-level political action to simultaneously tackle both legitimate ecological and socio-economic concerns can lead to uncertainty and frustration among farmers and other rural residents. This may result in a fundamental rejection of the transition towards climate neutrality and the enhancement of biodiversity by some stakeholders. Farmers' protests in many member states are pointers in this direction. Opinion research indicates that a sizeable share of the rural population perceives that rural areas are being overlooked by policymakers, for example when it comes to policy priorities or investments. Such sentiments are accompanied by significantly lower levels of trust in national governments and EU institutions, and lower levels of satisfaction with democracy compared to urban inhabitants (Eurofound et al. 2023).

Despite a range of EU rural development initiatives launched over the years, the challenges of rural areas seem to not having been addressed at the scale and with the urgency they warrant.[89] Introducing a "European Rural Deal" (Agora Energiewende 2024) as a flagship political project for the 2024–2029 EU legislative period could contribute to a long-term transformation of the economy accompanied by measures to improve social cohesion and to ensure that rural communities can sufficiently contribute to and participate in the benefits of a climate neutral society.

A European Rural Deal could include three broad priorities:

1. **Create future-oriented economic opportunities in rural areas**, including by mobilising investments into rural economic clusters and new value chains. This is to enable future-oriented business models where income is generated while contributing to climate neutrality, such as linking products cultivated on rewetted peatlands with the construction sector's demand for sustainably produced insulation material. Supporting the acquisition of new knowledge and skills, facilitating the establishment of new and young entrants into the land use sectors and rural economies, and adaptive labour arrangements will be necessary to both enhance social cohesion and ensure the uptake of new technologies.
2. **Support the development of infrastructure for the benefit of rural communities**, including high-capacity digital networks, clean mobility systems, such as public transport, electric-vehicle infrastructure and bike lanes, and renewable energy generation, such as wind, solar PV and residue-based biogas. These should be accompanied by arrangements that enable rural communities to receive an adequate share of the economic benefits of clean power generation.
3. **Maintain and enhance the attractiveness of rural living environments** by facilitating access to social services, including education, healthcare and culture. This could include introducing targeted public programmes, such as to support the modernisation of domestic heating systems and the combination of rooftop solar PV with electric vehicles.

The overarching objective of a European Rural Deal would be to ensure that the transition towards climate neutrality becomes an opportunity for rural

88 Defined as regions where residents live further than a 45-minute drive from the nearest city.

89 For example, the Cork Declaration 2.0 already in 2016 put forward a wide-ranging vision for the development of rural areas in Europe (ENRD 2016). More recently in 2021, the Commission identified a comprehensive set of rural challenges, opportunities and actions in its Long-term vision for EU's rural areas by 2040. A Rural Pact has been launched and associated actions have started to be implemented (European Commission 2024m). In 2023, member states adopted Council Conclusions calling on the European Commission to consider introducing a comprehensive EU rural strategy (Council of the EU 2023a). The European Parliament also supported increased priority on rural areas (European Parliament 2022).

communities across the EU. Such an initiative could help generate the necessary political momentum and help in developing and leveraging both public and private funding instruments. In that respect, it could act as a focal point in debates around the EU multiannual financial framework, articulating the needs of the land use sectors and rural areas in a comprehensive and solutions-oriented way. It could also help advance the debate about the further development of sustainable finance tools that enable private investments to be channelled towards the sustainability needs of the land use sectors.

6 References

Abdalla, N., Bürck, S., Fehrenbach, H., Köppen, S. & Staigl, T. J. (2022): *Biomethane in Europe*. IFEU, Institut für Energie und Umweltforschung. URL: https://www.ifeu.de/fileadmin/uploads/ifeu_ECF_biomethane_EU_final_01.pdf

Adhikari, K. & Hartemink, A. E. (2016): Linking soils to ecosystem services: A global review. *Geoderma*, *262*, 101–111. URL: https://doi.org/10.1016/j.geoderma.2015.08.009

Agora Energiewende (2023): *Breaking free from fossil gas. A new path to a climate-neutral Europe*. URL: https://static.agora-energiewende.de/fileadmin/Projekte/2021/2021_07_EU_GEXIT/A-EW_292_Breaking_free_WEB.pdf

Agora Energiewende (2024): *EU policies for climate neutrality in the decisive decade: 20 initiatives to advance solidarity, competitiveness and sovereignty*. URL: https://www.agora-energiewende.org/fileadmin/Projekte/2023/2023-05_EU_Big_Picture_2040/A-EW_318_EU_Big_Picture_2024_WEB.pdf

Agora Industry (2023): *Chemicals in transition*. URL: https://www.agora-energiewende.de/en/publications/chemicals-in-transition/

Agora Industry & Systemiq (2024): *Circular economy and net-zero industry: Potentials for energy-intensive value chains in Germany. English summary*. URL: https://www.agora-industry.org/fileadmin/Projekte/2022/2022-11_IND_Kreislaufwirtschaft/A-EW_320_Circular_Economy_Summary_EN_WEB.pdf

AgriDataSpace (2024): *AgriDataSpace*. URL: https://agridataspace-csa.eu/

Akert, F. S., Dorn, K., Frey, H., Hofstetter, P., Berard, J., Kreuzer, M. & Reidy, B. (2020): Farm-gate nutrient balances of grassland-based milk production systems with full- or part-time grazing and fresh herbage indoor feeding at variable concentrate levels. *Nutrient Cycling in Agroecosystems*, *117*(3), 383–400. URL: https://doi.org/10.1007/s10705-020-10072-y

Alarcón-Segura, V., Grass, I., Breustedt, G., Rohlfs, M. & Tscharntke, T. (2022): Strip intercropping of wheat and oilseed rape enhances biodiversity and biological pest control in a conventionally managed farm scenario. *Journal of Applied Ecology*, *59*(6), 1513–1523. URL: https://doi.org/10.1111/1365-2664.14161

Allen, M. R., Shine, K. P., Fuglestvedt, J. S., Millar, R. J., Cain, M., Frame, D. J. & Macey, A. H. (2018): A solution to the misrepresentations of CO2-equivalent emissions of short-lived climate pollutants under ambitious mitigation. *Npj Climate and Atmospheric Science*, *1*(1), 1–8. URL: https://doi.org/10.1038/s41612-018-0026-8

Amblard, L. (2019): Collective action for water quality management in agriculture: The case of drinking water source protection in France. *Global Environmental Change*, *58*. URL: https://doi.org/10.1016/j.gloenvcha.2019.101970

Ambrose, H., Dalby, F., Feilberg, A. & Kofoed, M. (2023): Additives and methods for the mitigation of methane emission from stored liquid manure. *Biosystems Engineering*, *229*, 209–245. URL: https://doi.org/10.1016/j.biosystemseng.2023.03.015

AMR Review (The Review on Antimicrobial Resistance) (2015): *Antimicrobials in Agriculture and the Environment: Reducing Unnecessary Use and Waste*. URL: https://amr-review.org/sites/default/files/Antimicrobials%20in%20agriculture%20and%20the%20environment%20-%20Reducing%20unnecessary%20use%20and%20waste.pdf

Anastasiou, E., Fountas, S., Voulgaraki, M., Psiroukis, V., Koutsiaras, M., Kriezi, O., Lazarou, E., Vatsanidou, A., Fu, L., Bartolo, F. D., Barreiro-Hurle, J. & Gómez-Barbero, M. (2023): Precision farming technologies for crop protection: A meta-analysis. *Smart Agricultural Technology*, *5*. URL: https://doi.org/10.1016/j.atech.2023.100323

Andersen, E. (2017): The farming system component of European agricultural landscapes. *European Journal of Agronomy*, *82*, 282–291. URL: https://doi.org/10.1016/j.eja.2016.09.011

Andersen, M. S. & Bonnis, G. (2021): *Climate mitigation co-benefits from sustainable nutrient management in agriculture: Incentives and opportunities*. OECD, Organisation for Economic Co-operation and Development. URL: https://doi.org/10.1787/a2960c54-en

Animal Protection Index (2023): *Methodology: World animal protection*. URL: https://api.worldanimalprotection.org/methodology

Ascoli, D., Plana, E., Oggioni, S. D., Tomao, A., Colonico, M., Corona, P., Giannino, F., Moreno, M., Xanthopoulos, G., Kaoukis, K., Athanasiou, M., Colaço, M. C., Rego, F., Sequeira, A. C., Acácio, V., Serra, M. & Barbati, A. (2023): Fire-smart solutions for sustainable wildfire risk prevention: Bottom-up initiatives meet top-down policies under EU green deal. *International Journal of Disaster Risk Reduction*, *92*, 103715. URL: https://doi.org/10.1016/j.ijdrr.2023.103715

Bach, M., Wilske, B. & Breuer, L. (2016): Current economic obstacles to biochar use in agriculture and climate change mitigation. *Carbon Management*, 7(3–4), 183–190. URL: https://doi.org/10.1080/17583004.2016.1213608

Bai, Y. & Cotrufo, M. F. (2022): Grassland soil carbon sequestration: Current understanding, challenges, and solutions. *Science*, *377*, 603–608. URL: https://doi.org/10.1126/science.abo2380

Bajzelj, B., McManus, W. & Parry, A. (2019): *Food waste in primary production in the UK*. WRAP, Waste and Resources Action Programme. URL: https://www.wrap.ngo/sites/default/files/2020-07/WRAP-food-waste-in-primary-production-in-the-UK.pdf

Baldock, D. & Bradley, H. (2023): *Transforming EU land use and the CAP: A post-2024 vision*. URL: https://ieep.eu/publications/transforming-eu-land-use-and-the-cap-a-post-2024-vision/

Balode, L., Bumbiere, K., Sosars, V., Valters, K. & Blumberga, D. (2024): Pros and Cons of Strategies to Reduce Greenhouse Gas Emissions from Peatlands: Review of Possibilities. *Applied Sciences*, *14*(6), 2260. URL: https://doi.org/10.3390/app14062260

Baral, A. & Malins, C. (2016): Additional supporting evidence for significant iLUC emissions of oilseed rape biodiesel production in the EU based on causal descriptive modeling approach. *GCB Bioenergy*, *8*(2), 382–391. URL: https://doi.org/10.1111/gcbb.12254

Barataud, F., Aubry, C., Wezel, A. & Mundler, P. (2014): Management of drinking water catchment areas in cooperation with agriculture and the specific role of organic farming. Experiences from Germany and France. *Land Use Policy*, *36*, 585–594. URL: https://doi.org/10.1016/j.landusepol.2013.10.010

Barnes, A. P., Soto, I., Eory, V., Beck, B., Balafoutis, A., Sánchez, B., Vangeyte, J., Fountas, S., van der Wal, T. & Gómez-Barbero, M. (2019): Exploring the adoption of precision agricultural technologies: A cross regional study of EU farmers. *Land Use Policy*, *80*, 163–174. URL: https://doi.org/10.1016/j.landusepol.2018.10.004

Barreiro-Hurle, J., Bogonos, M., Himics, M., Hristov, J., Pérez Domínguez, I., Sahoo, A., Salputra, G., Weiss, F., Baldoni, E. & Elleby, C. (2021): *Modelling environmental and climatic ambition in the agricultural sector with the CAPRI model: Exploring the potential effects of selected farm to fork and biodiversity strategies targets in the framework of the 2030 climate targets and the post 2020 Common Agricultural Policy.* European Commission. URL: https://op.europa.eu/en/publication-detail/-/publication/65064349-f0dd-11eb-a71c-01aa75ed71a1/language-en

Bartels, N., Dörr, J., Fehrmann, J., Gennen, K., Groen, E. C., Härtel, I., Henningsen, J., Herlitzius, T., Jeswein, T., Kunisch, M., Martini, D., Rauch, B., Roßner, S., Striller, B. & Walter, L.-S. (2020): *Machbarkeitsstudie zu staatlichen digitalen Datenplattformen für die Landwirtschaft*. URL: https://www.bmel.de/SharedDocs/Downloads/DE/_Digitalisierung/machbarkeitsstudie-agrardatenplattform.pdf

Barthelmes, A. (Ed.) (2018): *Reporting greenhouse gas emissions from organic soils in the European Union: Challenges and opportunities*. Proceedings of the Greifswald Mire Centre 02/2018. URL: https://greifswaldmoor.de/files/dokumente/GMC%20Schriften/18-02_Barthelmes_GMC.pdf

Basso, B., Dumont, B., Maestrini, B., Shcherbak, I., Robertson, G. P., Porter, J. R., Smith, P., Paustian, K., Grace, P. R., Asseng, S., Bassu, S., Biernath, C., Boote, K. J., Cammarano, D., De Sanctis, G., Durand, J.-L., Ewert, F., Gayler, S., Hyndman, D. W., … Rosenzweig, C. (2018): Soil Organic Carbon and Nitrogen Feedbacks on Crop Yields under Climate Change. *Agricultural & Environmental Letters*, *3*(1). URL: https://doi.org/10.2134/ael2018.05.0026

Battle, M., Pierce, B., Carter, M., Clarke, J. C., Fathman, L., Gertner, D. & Ignaszewski, E. (2022): *State of the industry report: Plant-based meat, seafood, eggs, and dairy*. Good Food Institute. URL: https://gfi.org/resource/plant-based-meat-eggs-and-dairy-state-of-the-industry-report/

Bayerisches Staatsministerium für Wohnen, Bau und Verkehr (2021): *Bayerisches Holzbauförderprogramm – BayFHolz*. URL: https://www.stmb.bayern.de/buw/bauthemen/gebaeudeundenergie/foerderprogramme/bayfholz/index.php

Bayr, U., Cobourn, K., Dieker, P., Fjellstad, W. J., Herzog, F. & Lankoski, J. (2023): *Guidelines for the development of an OECD farmland habitat biodiversity indicator*. OECD, Organisation for Economic Co-operation and Development. URL: https://doi.org/10.1787/09d45d55-en

Bazzanella, A. M. & Ausfelder, F. (2017): *Low carbon energy and feedstock for the European chemical industry. Technolgy study*. URL: https://dechema.de/dechema_media/Downloads/Positionspapiere/Technology_study_Low_carbon_energy_and_feedstock_for_the_European_chemical_industry.pdf

Bedoić, R., Čuček, L., Ćosić, B., Krajnc, D., Smoljanić, G., Kravanja, Z., Ljubas, D., Pukšec, T. & Duić, N. (2019): Green biomass to biogas: A study on anaerobic digestion of residue grass. *Journal of Cleaner Production*, *213*, 700–709. URL: https://doi.org/10.1016/j.jclepro.2018.12.224

Beillouin, D., Ben-Ari, T., Malézieux, E., Seufert, V. & Makowski, D. (2021): Positive but variable effects of crop diversification on biodiversity and ecosystem services. *Global Change Biology*, *27*(19), 4697–4710. URL: https://doi.org/10.1111/gcb.15747

Bellard, C., Bertelsmeier, C., Leadley, P., Thuiller, W. & Courchamp, F. (2012): Impacts of climate change on the future of biodiversity. *Ecology Letters*, *15*(4), 365–377. URL: https://doi.org/10.1111/j.1461-0248.2011.01736.x

Bellona (2022): *Addressing differences in permanence of Carbon Dioxide Removal.* URL: https://bellona.org/publication/addressing-differences-in-permanence-of-carbon-dioxide-removal

Benton, T. G., Vickery, J. A. & Wilson, J. D. (2003): Farmland biodiversity: Is habitat heterogeneity the key? *Trends in Ecology & Evolution*, *18*(4), 182–188. URL: https://doi.org/10.1016/S0169-5347(03)00011-9

Bertelsmann Stiftung (2022): *The Future of EU Cohesion*. URL: https://www.bertelsmann-stiftung.de/en/publications/publication/did/the-future-of-eu-cohesion

BEUC (European Consumer Organisation) (2020): *One bite at a time: Consumers and the transition to sustainable food.* URL: https://www.beuc.eu/press-releases/most-eu-consumers-open-eat-more-sustainably-face-hurdles-new-survey-shows

Biber, P., Felton, A., Nieuwenhuis, M., Lindbladh, M., Black, K., Bahýl', J., Bingöl, Ö., Borges, J. G., Botequim, B., Brukas, V., Bugalho, M. N., Corradini, G., Eriksson, L. O., Forsell, N., Hengeveld, G. M., Hoogstra-Klein, M. A., Kadıoğulları, A. İ., Karahalil, U., Lodin, I., … Tuček, J. (2020): Forest biodiversity, carbon sequestration, and wood production: Modeling synergies and trade-offs for ten forest landscapes across Europe. *Frontiers in Ecology and Evolution*, *8*, 547696. URL: https://doi.org/10.3389/fevo.2020.547696

Biffi, S., Chapman, P. J., Grayson, R. P. & Ziv, G. (2022): Soil carbon sequestration potential of planting hedgerows in agricultural landscapes. *Journal of Environmental Management*, *307*. URL: https://doi.org/10.1016/j.jenvman.2022.114484

Bisbis, M. B., Gruda, N. & Blanke, M. (2018): Potential impacts of climate change on vegetable production and product quality: A review. *Journal of Cleaner Production*, *170*, 1602–1620. URL: https://doi.org/10.1016/j.jclepro.2017.09.224

Blaydes, H., Potts, S. G., Whyatt, J. D. & Armstrong, A. (2021): Opportunities to enhance pollinator biodiversity in solar parks. *Renewable and Sustainable Energy Reviews*, *145*. URL: https://doi.org/10.1016/j.rser.2021.111065

Blickensdörfer, L., Schwieder, M., Pflugmacher, D., Nendel, C., Erasmi, S. & Hostert, P. (2022): Mapping of crop types and crop sequences with combined time series of Sentinel-1, Sentinel-2 and Landsat 8 data for Germany. *Remote Sensing of Environment*, *269*. URL: https://doi.org/10.1016/j.rse.2021.112831

Blomhoff, R., Andersen, R., Arnesen, E. K., Christensen, J. J., Eneroth, H., Erkkola, M., Gudanaviciene, I., Halldorsson, T. I., Høyer-Lund, A., Lemming, E. W., Meltzer, H. M., Pitsi, T., Schwab, U., Siksna, I., Thorsdottier, I. & Trolle, E. (2023): *Nordic Nutrition Recommendations 2023: Integrating environmental impacts*. Nordic Council of Ministers. URL: https://pub.norden.org/nord2023-003/nord2023-003.pdf

Bock, A.-K., Bontoux, L. & Rudkin, J.-E. (2022): *Concepts for a sustainable EU food system*. European Commission, Joint Research Centre. URL: https://doi.org/10.2760/381319

Böcker, T. & Finger, R. (2016): European Pesticide Tax Schemes in Comparison: An Analysis of Experiences and Developments. *Sustainability*, *8*(4), 378. URL: https://doi.org/10.3390/su8040378

BoerenNatuur (2023): *Collectieven: Agrarisch natuur—En landschapsbeheer*. URL: https://www.boerennatuur.nl/collectieven/

Böhm, C., Kanzler, M. & Pecenka, R. (2020): *Untersuchungen zur Ertragsleistung (Land Equivalent Ratio) von Agroforstsystemen* (Loseblatt # 35). URL: https://agroforst-info.de/wp-content/uploads/2021/03/35__Ertragsleistung.pdf

Bojnec, S. & Ferto, I. (2016): Export competitiveness of the European Union in fruit and vegetable products in the global markets. *Agricultural Economics*, *62*(7), 299–310. URL: https://doi.org/10.17221/156/2015-AGRICECON

Bolte, A., Höhl, M., Hennig, P., Schad, T., Kroiher, F., Seintsch, B., Englert, H. & Rosenkranz, L. (2021): *Zukunftsaufgabe Waldanpassung*. *76*, 12–16. URL: https://literatur.thuenen.de/digbib_extern/dn063364.pdf

Borrelli, P., Panagos, P., Alewell, C., Ballabio, C., de Oliveira Fagundes, H., Haregeweyn, N., Lugato, E., Maerker, M., Poesen, J., Vanmaercke, M. & Robinson, D. A. (2023): Policy implications of multiple concurrent soil erosion processes in European farmland. *Nature Sustainability*, *6*(1), 103–112. URL: https://doi.org/10.1038/s41893-022-00988-4

Böttcher, H., Reise, J. & Hennenberg, K. (2021): *Exploratory Analysis of an EU Sink and Restoration Target*. Oeko-Institut e.V. URL: https://www.oeko.de/fileadmin/oekodoc/GP-Sink-Target.pdf

Boumans, I. J. M. M., Schop, M., Bracke, M. B. M., de Boer, I. J. M., Gerrits, W. J. J. & Bokkers, E. A. M. (2022): Feeding food losses and waste to pigs and poultry: Implications for feed quality and production. *Journal of Cleaner Production*, *378*, 134623. URL: https://doi.org/10.1016/j.jclepro.2022.134623

Boyland, E., McGale, L., Maden, M., Hounsome, J., Boland, A. & Jones, A. (2022): Systematic review of the effect of policies to restrict the marketing of foods and non-alcoholic beverages to which children are exposed. *Obesity Reviews*, *23*(8), e13447. URL: https://doi.org/10.1111/obr.13447

Brandle, J. R., Hodges, L. & Zhou, X. H. (2004): Windbreaks in North American agricultural systems. *Agroforestry Systems*, *61*, 65–78. URL: https://doi.org/10.1023/B:AGFO.0000028990.31801.62

Brito, A. F., Almeida, K. V. & Oliveira, A. S. (2022): Production performance, nutrient use efficiency, and predicted enteric methane emissions in dairy cows under confinement or grazing management system. *Translational Animal Science*, *6*(2). URL: https://doi.org/10.1093/tas/txac028

Britz, W. & Delzeit, R. (2013): The impact of German biogas production on European and global agricultural markets, land use and the environment. *Energy Policy*, *62*, 1268–1275. URL: https://doi.org/10.1016/j.enpol.2013.06.123

Brundtland, G. H. et al. (1987): *Report of the World Commission on Environment and Development: Our Common Future*. URL: https://www.un-documents.net/our-common-future.pdf

Bui, L. P., Pham, T. T., Wang, F., Chai, B., Sun, Q., Hu, F. B., Lee, K. H., Guasch-Ferre, M. & Willett, W. C. (2024): Planetary Health Diet Index and risk of total and cause-specific mortality in three prospective cohorts. *The American Journal of Clinical Nutrition*, *120*(1), 80–91. URL: https://doi.org/10.1016/j.ajcnut.2024.03.019

Bumharter, C., Bolonio, D., Amez, I., García Martínez, M. J. & Ortega, M. F. (2023): New opportunities for the European Biogas industry: A review on current installation development, production potentials and yield improvements for manure and agricultural waste mixtures. *Journal of Cleaner Production*, *388*. URL: https://doi.org/10.1016/j.jclepro.2023.135867

Buschmann, C., Röder, N., Berglund, K., Berglund, Ö., Lærke, P. E., Maddison, M., Mander, Ü., Myllys, M., Osterburg, B. & Van Den Akker, J. J. H. (2020): Perspectives on agriculturally used drained peat soils: Comparison of the socioeconomic and ecological business environments of six European regions. *Land Use Policy*, *90*. URL: https://doi.org/10.1016/j.landusepol.2019.104181

Cady, R. A. (2020): *A literature review of GWP*: A proposed method for estimating global warming potential (GWP*) of short-lived climate pollutants like methane*. Global Dairy Platform. URL: https://www.globaldairyplatform.com/wp-content/uploads/2020/11/literature-review-of-gwp-nov_20.pdf

Cahalan, E., Ernfors, M., Müller, C., Devaney, D., Laughlin, R. J., Watson, C. J., Hennessy, D., Grant, J., Khalil, M. I., McGeough, K. L. & Richards, K. G. (2015): The effect of the nitrification inhibitor dicyandiamide (DCD) on nitrous oxide and methane emissions after cattle slurry application to Irish grassland. *Agriculture, Ecosystems & Environment*, *199*, 339–349. URL: https://doi.org/10.1016/j.agee.2014.09.008

Cain, M., Lynch, J., Allen, M. R., Fuglestvedt, J. S., Frame, D. J. & Macey, A. H. (2019): Improved calculation of warming-equivalent emissions for short-lived climate pollutants. *Npj Climate and Atmospheric Science*, *2*(1), 1–7. URL: https://doi.org/10.1038/s41612-019-0086-4

Caldeira, C., De Laurentiis, V., Ghose, A., Corrado, S. & Sala, S. (2021): Grown and thrown: Exploring approaches to estimate food waste in EU countries. *Resources, Conservation and Recycling*, *168*, 105426. URL: https://doi.org/10.1016/j.resconrec.2021.105426

Caldeira, C., De Laurentiis, V. & Sala, S. (2019): *Suggestions to improve data coverage and comparability in food waste accounting studies across the EU*. European Commission, Joint Research Centre. URL: https://doi.org/10.2760/850030

Caleffi, S., Hawkes, C. & Walton, S. (2023): *45 Actions to orient food systems towards environmental sustainability: Co-benefits and trade-offs*. Centre for Food Policy, City University London. URL: https://openaccess.city.ac.uk/id/eprint/30532/

Calvert, E. (2021): *Food marketing to children needs rules with teeth: A snapshot report about how self-regulation fails to prevent unhealthy foods to be marketed to children*. BEUC, Bureau Européen des Unions de Consommateurs, European Consumer Organisation. URL: https://www.beuc.eu/publications/beuc-x-2021-084_food_marketing_to_children_needs_rules_with_teeth.pdf

Candeal, T., Brüggemann, N., Bruns, H., Casonato, C., Diercxsens, C., Garcia, H. L., Gil, J. M., Haglund, Y., Kaptan, G., Kasza, G., Mikkelsen, B. E., Obersteiner, G., Pires, I. M., Swannell, R., Vainioranta, J., Van, H. E., Vittuari, M., Watanabe, K. & Sala, S. (2023): *Tools, best practices and recommendations to reduce consumer food waste: A compendium*. European Commission, Joint Research Centre. URL: https://doi.org/10.2760/967005

Candel, J., Pe'er, G. & Finger, R. (2023): Science calls for ambitious European pesticide policies. *Nature Food*, *4*. URL: https://doi.org/10.1038/s43016-023-00727-8

Carbon Gap (2024): *Envisioning a carbon removal strategy for Europe*. 18 March 2024. URL: https://carbongap.org/eu-cdr-strategy/

CBD (Convention on Biological Diversity) (1993): *Convention on Biological Diversity*. URL: https://www.cbd.int/convention/text

CBD (Convention on Biological Diversity) (2022): *Kunming-Montreal Global Biodiversity Framework. CBD/COP/15/L.25*. URL: https://www.unep.org/resources/kunming-montreal-global-biodiversity-framework

Ceballos, G., Ehrlich, P. R., Barnosky, A. D., García, A., Pringle, R. M. & Palmer, T. M. (2015): Accelerated modern human-induced species losses: Entering the sixth mass extinction. *Science Advances*, *1*(5), e1400253. URL: https://doi.org/10.1126/sciadv.1400253

CEJA (European council of young farmers) (2023): *Smart Farmers for Smart Farming*. URL: https://wordpress.ceja.eu/wp-content/uploads/2023/05/CEJA-policy-paper-Smart-farmers-for-smart-farming-May-2023.pdf

Chadwick, D., Sommer, S., Thorman, R., Fangueiro, D., Cardenas, L., Amon, B. & Misselbrook, T. (2011): Manure management: Implications for greenhouse gas emissions. *Animal Feed Science and Technology*, *166–167*, 514–531. URL: https://doi.org/10.1016/j.anifeedsci.2011.04.036

Chakraborty, D., Ciceu, A., Ballian, D., Benito Garzón, M., Bolte, A., Bozic, G., Buchacher, R., Čepl, J., Cremer, E., Ducousso, A., Gaviria, J., George, J. P., Hardtke, A., Ivankovic, M., Klisz, M., Kowalczyk, J., Kremer, A., Lstibůrek, M., Longauer, R., … Schueler, S. (2024): Assisted tree migration can preserve the European forest carbon sink under climate change. *Nature Climate Change*, 1–8. URL: https://doi.org/10.1038/s41558-024-02080-5

Chaplin-Kramer, R., O'Rourke, S., Blitzer, E. J. & Kremen, C. (2011): A meta-analysis of crop pest and natural enemy response to landscape complexity. *Ecology Letters*, *14*, 922–932. URL: https://doi.org/10.1111/j.1461-0248.2011.01642.x

Chaplot, V. & Smith, P. (2023): Cover crops do not increase soil organic carbon stocks as much as has been claimed: What is the way forward? *Global Change Biology*. URL: https://doi.org/10.1111/gcb.16917

Chatellier, V. & Guyomard, H. (2023): Supporting European farmers' incomes through Common Agricultural Policy direct aids: Facts and questions. *Review of Agricultural, Food and Environmental Studies*, *104*(1), 87–99. URL: https://doi.org/10.1007/s41130-023-00192-8

Chatham House (2023): *The emerging global crisis of land use*. 22 November 2023. URL: https://www.chathamhouse.org/2023/11/emerging-global-crisis-land-use

Chaudhary, A., Burivalova, Z., Koh, L. P. & Hellweg, S. (2016): Impact of forest management on species richness: Global meta-analysis and economic trade-offs. *Scientific Reports*, *6*(1), 23954. URL: https://doi.org/10.1038/srep23954

Chen, C., Loft, L. & Matzdorf, B. (2023): Lost in action: Climate friendly use of European peatlands needs coherence and incentive-based policies. *Environmental Science & Policy*, *145*, 104–115. URL: https://doi.org/10.1016/j.envsci.2023.04.010

Cheng, M., McCarl, B. & Fei, C. (2022): Climate change and livestock production: A literature review. *Atmosphere*, *13*(1). URL: https://doi.org/10.3390/atmos13010140

Christensen, A. (2021): *Transportation Carbon Intensity Targets for the European Union*. URL: https://theicct.org/wp-content/uploads/2021/12/GAMS-EU-fuels-modeling-consultant-report-Aug2021.pdf

CLC (Corine Land Cover) (2018): *CORINE Land Cover 2018 (vector/raster 100 m), Europe, 6-yearly*. URL: https://land.copernicus.eu/en/products/corine-land-cover/clc2018

Clough, Y., Kirchweger, S. & Kantelhardt, J. (2020): Field sizes and the future of farmland biodiversity in European landscapes. *Conservation Letters*, *13*(6). URL: https://doi.org/10.1111/conl.12752

CONCITO (2023): *The future role of BECCS and DACCS in the EU: Potential and risks*. 28 June 2023. URL: https://concito.dk/en/udgivelser/the-future-role-of-beccs-and-daccs-in-the-eu-potential-and-risks

CONCITO (2024): *Towards a sustainable deployment of BioCCS in the EU*. 28 May 2024. URL: https://concito.dk/en/udgivelser/towards-a-sustainable-deployment-of-bioccs-in-the-eu

Cooper, T., Hart, K. & Baldock, D. (2009): *The Provision of Public Goods through Agriculture in the European Union*. IEEP, Institute for European Environmental Policy. URL: https://ieep.eu/publications/the-provision-of-public-goods-through-agriculture-in-the-european-union/

Corsus GmbH (2024): *Calculation of greenhouse gas emissions of various protein rich foods. Expertise on behalf of Agora Agrar*. Unpublished.

Council of Europe (1976): *European Convention for the Protection of Animals kept for Farming Purposes*. URL: https://rm.coe.int/1680076da6

Council of the EU (2022): *Porto Social Summit: One year later Employment, Social Policy, Health and Consumer Affairs Council (Social)*. 16 June 2022. URL: https://www.consilium.europa.eu/en/meetings/epsco/2022/06/16/

Council of the EU (2023a): *A long-term vision for the EU's rural areas: Council approves conclusions*. URL: https://www.consilium.europa.eu/en/press/press-releases/2023/11/20/a-long-term-vision-for-the-eu-s-rural-areas-council-approves-conclusions/

Council of the EU (2023b): *Council Recommendation of 30 January 2023 on adequate minimum income ensuring active inclusion. 2023/C 41/01*. URL: https://eur-lex.europa.eu/legal-content/en/ALL/?uri=CELEX:32023H0203(01)

Council of the EU (2024a): *Air quality: Council and Parliament strike deal to strengthen standards in the EU*. URL: https://www.consilium.europa.eu/en/press/press-releases/2024/02/20/air-quality-council-and-parliament-strike-deal-to-strengthen-standards-in-the-eu/?

Council of the EU (2024b): *Council gives final green light to a targeted review of the common agricultural policy*. URL: https://www.consilium.europa.eu/en/press/press-releases/2024/05/13/council-gives-final-green-light-to-a-targeted-review-of-the-common-agricultural-policy/

Crippa, M., Guizzardi, D., Solazzo, E., Ferrario-Monforti, F., Tubiello, F. N. & Leip, A. (2021a): *EDGAR-FOOD emission data*. URL: https://doi.org/10.6084/M9.FIGSHARE.13476666

Crippa, M., Solazzo, E., Guizzardi, D., Monforti-Ferrario, F., Tubiello, F. N. & Leip, A. (2021b): Food systems are responsible for a third of global anthropogenic GHG emissions. *Nature Food*, *2*, 198–209. URL: https://doi.org/10.1038/s43016-021-00225-9

Crippa, M., Solazzo, E., Guizzardi, D., Van Dingenen, R. & Leip, A. (2022): Air pollutant emissions from global food systems are responsible for environmental impacts, crop losses and mortality. *Nature Food*, *3*(11), 942–956. URL: https://doi.org/10.1038/s43016-022-00615-7

Cuadros-Casanova, I., Cristiano, A., Biancolini, D., Cimatti, M., Sessa, A. A., Mendez Angarita, V. Y., Dragonetti, C., Pacifici, M., Rondinini, C. & Di Marco, M. (2023): Opportunities and challenges for Common Agricultural Policy reform to support the European Green Deal. *Conservation Biology*, *37*(3), e14052. URL: https://doi.org/10.1111/cobi.14052

d'Andrimont, R., Verhegghen, A., Lemoine, G., Kempeneers, P., Meroni, M. & van der Velde, M. (2021): From parcel to continental scale: A first European crop type map based on Sentinel-1 and LUCAS Copernicus in-situ observations. *Remote Sensing of Environment*, *266*. URL: https://doi.org/10.1016/j.rse.2021.112708

Dahms, T., Oehmke, C., Kowatsch, A., Abel, S., Wichmann, S., Wichtmann, W. & Schröder, C. (2017): *Halmgutartige Festbrennstoffe aus nassen Mooren. Paludi-Pellets-Broschüre*. University of Greifswald, Institute of Botany and Landscape Ecology. URL: https://www.moorwissen.de/files/doc/publikationen/paludi_pellets_broschuere/downloads/Dahms%20et%20al.%20%282017%29%20Paludi-Pellets-Brosch%C3%BCre.pdf

Dalby, F. R., Hansen, M. J., Guldberg, L. B., Hafner, S. D. & Feilberg, A. (2023): Simple Management Changes Drastically Reduce Pig House Methane Emission in Combined Experimental and Modeling Study. *Environmental Science & Technology*, *57*(9), 3990–4002. URL: https://doi.org/10.1021/acs.est.2c08891

Dale, B. E., Bozzetto, S., Couturier, C., Fabbri, C., Hilbert, J. A., Ong, R., Richard, T., Rossi, L., Thelen, K. D. & Woods, J. (2020): The potential for expanding sustainable biogas production and some possible impacts in specific countries. *Biofuels, Bioproducts and Biorefining*, *14*(6), 1335–1347. URL: https://doi.org/10.1002/bbb.2134

Dauber, J., Jones, M. B. & Stout, J. C. (2010): The impact of biomass crop cultivation on temperate biodiversity. *GCB Bioenergy*, *2*(6), 289–309. URL: https://doi.org/10.1111/j.1757-1707.2010.01058.x

De Laurentiis, V., Biganzoli, F., Valenzano, A., Caldeira, C. & Sala, S. (2023): *Building a balancing system for food waste accounting at national level: Model updates version 2.0*. European Commission, Joint Research Centre. URL: https://doi.org/10.2760/374244

De Laurentiis, V., Orza, V. & Sala, S. (2024): *Modelling the land footprint of EU consumption - Methodology and results of the LAFO model version 2.0.* Publications Office of the European Union. URL: https://doi.org/10.2760/97417

De Rosa, D., Ballabio, C., Lugato, E., Fasiolo, M., Jones, A. & Panagos, P. (2024): Soil organic carbon stocks in European croplands and grasslands: How much have we lost in the past decade? *Global Change Biology*, *30*(1), e16992. URL: https://doi.org/10.1111/gcb.16992

de Vries, W., Römkens, P., Kros, J., Voogd, J. C. & Schulte-Uebbing, L. F. (2022): *Impacts of nutrients and heavy metals in European agriculture: Current and critical inputs in relation to air, soil and water quality.* ETC DI Report 2022/01. URL: https://www.eionet.europa.eu/etcs/etc-di/products/impacts-of-nutrients-and-heavy-metals-in-european-agriculture-current-and-critical-inputs-in-relation-to-air-soil-and-water-quality

de Vries, W., Schulte-Uebbing, L., Kros, H., Voogd, J. C. & Louwagie, G. (2021): Spatially explicit boundaries for agricultural nitrogen inputs in the European Union to meet air and water quality targets. *The Science of the Total Environment*, *786*. URL: https://doi.org/10.1016/j.scitotenv.2021.147283

Demartini, E., Gaviglio, A., Gelati, M. & Cavicchioli, D. (2016): The effect of biogas production on farmland rental prices: Empirical evidences from Northern Italy. *Energies*, *9*(11), 965. URL: https://doi.org/10.3390/en9110965

Détang-Dessendre, C., Geerling-Eiff, F., Guyomard, H. & Poppe, K. (2018): *EU Agriculture and Innovation: What Role for the CAP?* INRA and WUR. URL: https://edepot.wur.nl/447423

Dik, L., Westerink, J., van der Linde, A. W., Olieman, A. A. M., Termeer, C. J. A. M. & Runhaar, H. A. C. (2023): Professional farmer collectives for effective agri-environmental management: An assessment. *International Journal of Agricultural Sustainability*, *21*(1), 2224648. URL: https://doi.org/10.1080/14735903.2023.2224648

Ding, Y., Huang, X., Li, Y., Liu, H., Zhang, Q., Liu, X., Xu, J. & Di, H. (2021): Nitrate leaching losses mitigated with intercropping of deep-rooted and shallow-rooted plants. *Journal of Soils and Sediments*, *21*(1), 364–375. URL: https://doi.org/10.1007/s11368-020-02733-w

Domke, N. (2023): *Opportunity Costs of Rewetting Agriculturally Used Organic Soils in Germany.* Humboldt University. Unpublished.

Don, A., Seidel, F., Leifeld, J., Kätterer, T., Martin, M., Pellerin, S., Emde, D., Seitz, D. & Chenu, C. (2023): Carbon sequestration in soils and climate change mitigation: Definitions and pitfalls. *Global Change Biology*, *30*(1). URL: https://doi.org/10.1111/gcb.16983

Donat, M., Geistert, J., Grahmann, K., Bloch, R. & Bellingrath-Kimura, S. D. (2022): Patch cropping: A new methodological approach to determine new field arrangements that increase the multifunctionality of agricultural landscapes. *Computers and Electronics in Agriculture*, *197*. URL: https://doi.org/10.1016/j.compag.2022.106894

Dondini, M., Martin, M., De Camilis, C., Uwizeye, A., Soussana, J.-F., Robinson, T. & Steinfeld, H. (2023): *Global assessment of soil carbon in grasslands: From current stock estimates to sequestration potential.* Paper No. 187. FAO Animal Production and Health. URL: https://doi.org/10.4060/cc3981en

Drexler, S., Gensior, A. & Don, A. (2021): Carbon sequestration in hedgerow biomass and soil in the temperate climate zone. *Regional Environmental Change*, *21*(3). URL: https://doi.org/10.1007/s10113-021-01798-8

Duscha, V., Wachsmuth, J., Eckstein, J. & Pfluger, B. (2019): *GHG-neutral EU2050: A scenario of an EU with net-zero greenhouse gas emissions and its implications. Full Report*. URL: https://www.umweltbundesamt.de/sites/default/files/medien/1410/publikationen/2019-11-26_cc_40-2019_ghg_neutral_eu2050_0.pdf

EASAC (European Academics Science Advisory Council) (2022): *Forest bioenergy update: BECCS and its role in integrated assessment models*. URL: https://easac.eu/publications/details/forest-bioenergy-update-beccs-and-its-role-in-integrated-assessment-models

ECA (European Court of Auditors) (2016): *Is the Commission's system for performance measurement in relation to farmers' incomes well designed and based on sound data?* Special report 1/2016. URL: https://www.eca.europa.eu/en/Pages/Report.aspx?did=35782&TermStoreId=8935807f-8495-4a93-a302-f4b76776d8ea&TermSetId=49e662c4-f172-43ae-8a5e-7276133de92c&TermId=5f6589a2-5a2e-4ae8-8cc6-e05bf544b71f

ECA (European Court of Auditors) (2022): *Climate spending in the 2014-2020 EU budget: Not as high as reported.* Special report 09/2022. URL: https://www.eca.europa.eu/en/Pages/Report.aspx?did=61103&TermStoreId=8935807f-8495-4a93-a302-f4b76776d8ea&TermSetId=49e662c4-f172-43ae-8a5e-7276133de92c&TermId=5f6589a2-5a2e-4ae8-8cc6-e05bf544b71f

ECA (European Court of Auditors) (2023a): *EU climate and energy targets.* Special report 18/2023. URL: https://www.eca.europa.eu/en/publications/sr-2023-18

ECA (European Court of Auditors) (2023b): *The EU's support for sustainable biofuels in transport*. Special report 29/2023. URL: https://www.eca.europa.eu/en/publications/sr-2023-29

ECDC, EFSA & EMA (European Centre for Disease Prevention and Control, European Food Safety Authority & European Medicines Agency) (2021): *JIACRA III: Antimicrobial consumption and resistance in bacteria from humans and animals*. URL: https://www.ecdc.europa.eu/en/publications-data/third-joint-interagency-antimicrobial-consumption-and-resistance-analysis-report

ECDC, EFSA & EMA (European Centre for Disease Prevention and Control, European Food Safety Authority & European Medicines Agency) (2024): *Antimicrobial consumption and resistance in bacteria from humans and food- producing animals.* URL: https://www.efsa.europa.eu/en/efsajournal/pub/8589

ECORYS, Kantar Public, University of Helsinki & European Commission (2021): *Study on the exposure of children to linear, non-linear and online marketing of foods high in fat, salt or sugar. Final report*. URL: https://data.europa.eu/doi/10.2875/928620

Edenhofer, O., Franks, M., Kalkuhl, M. & Runge-Metzger, A. (2023): *On the governance of carbon sioxide removal: A public economics perspective.* CESifo Working Paper No. 10370. URL: https://www.cesifo.org/en/publications/2023/working-paper/governance-carbon-dioxide-removal-public-economics-perspective

EEA (European Environment Agency) (2017): *Climate change, impacts and vulnerability in Europe 2016: An indicator-based report.* EEA Report 1/2017. URL: https://www.eea.europa.eu/publications/climate-change-impacts-and-vulnerability-2016

EEA (European Environment Agency) (2019a): *Healthy environment, healthy lives: How the environment influences health and well-being in Europe*. URL: https://www.eea.europa.eu/publications/healthy-environment-healthy-lives

EEA (European Environment Agency) (2019b): *The European environment: State and outlook 2020. Knowledge for transition to a sustainable Europe*. URL: https://www.eea.europa.eu/publications/soer-2020

EEA (European Environment Agency) (2020): *State of nature in the EU*. URL: https://www.eea.europa.eu/publications/state-of-nature-in-the-eu-2020

EEA (European Environment Agency) (2021): *Nature-based solutions in Europe: Policy, knowledge and practice for climate change adaptation and disaster risk reduction*. URL: https://www.eea.europa.eu/publications/nature-based-solutions-in-europe/

EEA (European Environment Agency) (2022a): *Carbon sinks and sources*. URL: https://forest.eea.europa.eu/topics/forest-and-climate/carbon-sink

EEA (European Environment Agency) (2022b): *Carbon stocks and sequestration in terrestrial and marine ecosystems: A lever for nature restoration?* URL: https://www.eea.europa.eu/publications/carbon-stocks-and-sequestration-rates

EEA (European Environment Agency) (2022c): *Historical (1990-2020) and projected (2020-2040) emissions from the agriculture sector in the EU-27.* URL: https://www.eea.europa.eu/data-and-maps/figures/historical-1990-2020-and-projected

EEA (European Environment Agency) (2022d): *Trends and projections in Europe 2022.* EEA Report 10/2022. URL: https://www.eea.europa.eu/publications/trends-and-projections-in-europe-2022

EEA (European Environment Agency) (2023a): *European Union 8th Environment Action Programme*. URL: https://www.eea.europa.eu/publications/european-union-8th-environment-action-programme

EEA (European Environment Agency) (2023b): *Greenhouse gas emissions from agriculture in Europe*. URL: https://www.eea.europa.eu/en/analysis/indicators/greenhouse-gas-emissions-from-agriculture

EEA (European Environment Agency) (2023c): *Greenhouse gas emissions from land use, land use change and forestry in Europe*. URL: https://www.eea.europa.eu/en/analysis/indicators/greenhouse-gas-emissions-from-land

EEA (European Environment Agency) (2023d): *The European Biomass Puzzle*. URL: https://www.eea.europa.eu/publications/the-european-biomass-puzzle

EEA (European Environment Agency) (2023e): *Transforming Europe's food system: Assessing the EU policy mix.* EEA report 14/2022. URL: https://www.eea.europa.eu/publications/transforming-europes-food-system

EEA (European Environment Agency) (2024a): *European Climate Risk Assessment*. URL: https://www.eea.europa.eu/publications/european-climate-risk-assessment

EEA (European Environment Agency) (2024b): *Europe's sustainability transitions outlook*. URL: https://www.eea.europa.eu/publications/europes-sustainability-transitions-outlook

EEA (European Environment Agency) (2024c): *National emissions reported to the UNFCCC and to the EU Greenhouse Gas Monitoring Mechanism 1985-2022*. URL: https://doi.org/10.2909/6331F651-8863-4656-A911-669F2A332A1E

EFSA (European Food Safety Authority) (2023): *Animal welfare*. URL: https://www.efsa.europa.eu/en/topics/topic/animal-welfare

EFSA (European Food Safety Authority) Panel on Animal Health and Animal Welfare (AHAW), Nielsen, S. S., Alvarez, J., Bicout, D. J., Calistri, P., Canali, E., Drewe, J. A., Garin-Bastuji, B., Gonzales Rojas, J. L., Gortázar Schmidt, C., Herskin, M., Michel, V., Miranda Chueca, M. Á., Padalino, B., Roberts, H. C., Spoolder, H., Stahl, K., Velarde, A., Viltrop, A., ... Winckler, C. (2023): Welfare of dairy cows summary. *EFSA Journal*, *21*(5). URL: https://doi.org/10.2903/j.efsa.2023.7993

EFSA (European Food Safety Authority) Panel on Nutrition, Novel Foods and Food Allergens (NDA) (2022): Scientific advice related to nutrient profiling for the development of harmonised mandatory front-of-pack nutrition labelling and the setting of nutrient profiles for restricting nutrition and health claims on foods. *EFSA Journal*, *20*(4). URL: https://doi.org/10.2903/j.efsa.2022.7259

EFSA (European Food Safety Authority) Panel on Biological Hazards (BIOHAZ), Ricci, A., Allende, A., Bolton, D., Chemaly, M., Davies, R., Fernández Escámez, P. S., Gironés, R., Herman, L., Koutsoumanis, K., Lindqvist, R., Nørrung, B., Robertson, L., Ru, G., Sanaa, M., Skandamis, P., Snary, E., Speybroeck, N., Kuile, B. T., Simmons, M. (2018): Updated quantitative risk assessment (QRA) of the BSE risk posed by processed animal protein (PAP). *EFSA Journal. European Food Safety Authority, 16*(7), e05314. URL: https://doi.org/10.2903/j.efsa.2018.5314

Einarsson, R. & Persson, U. M. (2017): Analyzing key constraints to biogas production from crop residues and manure in the EU: A spatially explicit model. *PLOS ONE*, *12*(1). URL: https://doi.org/10.1371/journal.pone.0171001

EIT FOOD (2022): *Protein Diversification. An EIT FOOD White Paper*. URL: https://www.eitfood.eu/files/EIT-FOOD-WHITE-PAPER-PROTEIN-DIVERSITICATION-2022_FINAL15-12-22.pdf

Ekardt, F., Günther, P., Hagemann, K., Garske, B., Heyl, K. & Weyland, R. (2023): Legally binding and ambitious biodiversity protection under the CBD, the global biodiversity framework, and human rights law. *Environmental Sciences Europe*, *35*(1), 80. URL: https://doi.org/10.1186/s12302-023-00786-5

Energy Transition Commission (2021): *Making Clean Electrification Possible: 30 Years to Electrify the Global Economy*. URL: https://www.energy-transitions.org/publications/making-clean-electricity-possible/#download-form

ENRD (European Network for Rural Development) (2016): *Cork 2.0 and the Future of Rural Development*. URL: https://enrd.ec.europa.eu/cork-20-and-future-rural-development_en

Ertl, P., Zebeli, Q., Zollitsch, W. & Knaus, W. (2015): Feeding of by-products completely replaced cereals and pulses in dairy cows and enhanced edible feed conversion ratio. *Journal of Dairy Science*, *98*(2), 1225–1233. URL: https://doi.org/10.3168/jds.2014-8810

ESABCC (European Scientific Advisory Board on Climate Change) (2023): *Scientific advice for the determination of an EU-wide 2040 climate target and a greenhouse gas budget for 2030–2050*. URL: https://climate-advisory-board.europa.eu/reports-and-publications/scientific-advice-for-the-determination-of-an-eu-wide-2040

ESABCC (European Scientific Advisory Board on Climate Change) (2024): *Towards EU climate neutrality: Progress, policy gaps and opportunities*. 17 January 2024. URL: https://climate-advisory-board.europa.eu/reports-and-publications/towards-eu-climate-neutrality-progress-policy-gaps-and-opportunities

ESC (European Social Charter) (1961): *Complete List of the Council of Europe's treaties*. URL: https://www.coe.int/en/web/conventions/full-list

ETH Zürich (2024): *SEED Biocomplexity*. URL: https://seed-index.com/

EU-OSHA (European Agency for Safety and Health at Work) (2019): *Exposure to biological agents and related health problems in animal-related occupations*. URL: https://osha.europa.eu/en/publications/exposure-biological-agents-and-related-health-problems-animal-related-occupations

EU-OSHA (European Agency for Safety and Health at Work) (2020): *The future of agriculture and forestry: Implications for managing worker safety and health*. URL: https://osha.europa.eu/en/publications/future-agriculture-and-forestry-implications-managing-worker-safety-and-health

Eurofound, Mascherini, M., Hyland, M., Hingre, G. et al. (2023): *Bridging the rural-urban divide: Addressing inequalities and empowering communities*. URL: https://data.europa.eu/doi/10.2806/647715

European Commission (2018a): *A sustainable bioeconomy for Europe: Strengthening the connection between economy, society and the environment. Updated Bioeconomy Strategy*. URL: https://knowledge4policy.ec.europa.eu/publication/sustainable-bioeconomy-europe-strengthening-connection-between-economy-society_en

European Commission (2018b): *Bioeconomy: The European way to use our natural resources. Action Plan 2018*. European Commission, Directorate-General for Research and Innovation. URL: https://data.europa.eu/doi/10.2777/79401

European Commission (2019a): *Commission Staff Working Document: EU green public procurement criteria for food, catering services and vending machines. SWD(2019) 366 final*. URL: https://circabc.europa.eu/rest/download/9cd7f542-d33c-43f6-91af-b3838c08c395?ticket=

European Commission (2019b): *The European Green Deal*. URL: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2019%3A640%3AFIN

European Commission (2020a): *A Farm to Fork Strategy for a fair, healthy and environmentally-friendly food system. COM/2020/381 final*. URL: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52020DC0381

European Commission (2020b): *Communication. A European strategy for data. COM(2020) 66 final*. URL: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52020DC0066

European Commission (2020c): *EU agriculture in numbers: Performance on the nine specific objectives of the CAP*. European Commission, Directorate-General for Agriculture and Rural Development. URL: https://agriculture.ec.europa.eu/system/files/2020-05/analytical-factsheet-eu-level_en_0.pdf

European Commission (2021a): *Animal welfare: Revision of EU legislation*. Animal Welfare – Revision of EU Legislation. URL: https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12950-Animal-welfare-revision-of-EU-legislation_en

European Commission (2021b): *Communication. A long-term Vision for the EU's rural areas: Towards stronger, connected, resilient and prosperous rural areas by 2040. COM(2021) 345 final*. URL: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021DC0345

European Commission (2021c): *Communication. EU Soil Strategy for 2030: Reaping the benefits of healthy soils for people, food, nature and climate. COM(2021) 699 final*. URL: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021DC0699

European Commission (2021d): *Communication. Pathway to a Healthy Planet for All EU Action Plan: 'Towards Zero Pollution for Air, Water and Soil'. COM/2021/400 final*. URL: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021DC0400&qid=1623311742827

European Commission (2021e): *Communication. Sustainable Carbon Cycles. COM(2021) 800 final*. URL: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021DC0800

European Commission (2021f): *EU Biodiversity Strategy for 2030: Bringing nature back into our lives*. European Commission, Directorate-General for Environment. URL: https://data.europa.eu/doi/10.2779/677548

European Commission (2021g): *Inception impact assessment: Ares(2021)5902055*. URL: https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/13174-Sustainable-EU-food-system-new-initiative_en

European Commission (2021h): *Legislative framework for sustainable food systems (FSFS)*. URL: https://food.ec.europa.eu/horizontal-topics/farm-fork-strategy/legislative-framework_en

European Commission (2021i): *New EU Forest Strategy for 2030*. URL: https://eur-lex.europa.eu/resource.html?uri=cellar:0d918e07-e610-11eb-a1a5-01aa75ed71a1.0001.02/DOC_1&format=PDF

European Commission (2021j): *Political agreement on new Common Agricultural Policy*. URL: https://ec.europa.eu/commission/presscorner/detail/en/ip_21_2711

European Commission (2021k): *Wood Resource Balances of European Union 2009-2017*. URL: https://knowledge4policy.ec.europa.eu/sites/default/files/WRB_EU_v2021.pdf

European Commission (2022a): *Commission Response to Council Decision (EU) 2022/2572 of 19 December 2022*. URL: https://food.ec.europa.eu/document/download/f9c54e6c-023c-4399-8c24-6c1920efeeba_en

European Commission (2022b): *Commission Staff Working Document: Fitness Check of the EU Animal Welfare legislation. SWD(2022) 328 final*. URL: https://food.ec.europa.eu/system/files/2022-10/aw_eval_revision_swd_2022-328_en.pdf

European Commission (2022c): *Commission Staff Working Document Impact Assessment Report. Annex VI-b Accompanying the proposal for a Regulation of the European Parliament and of the Council on nature restoration. SWD/2022/167 final*. URL: https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=SWD%3A2022%3A167%3AFIN

European Commission (2022d): *Communication. REPowerEU Plan*. URL: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2022%3A230%3AFIN&qid=1653033742483

European Commission (2022e): *EU Protein Balance Sheet 2022*. URL: https://agriculture.ec.europa.eu/data-and-analysis/markets/overviews/balance-sheets-sector/oilseeds-and-protein-crops_en

European Commission (2022f): *Farm to Fork: New rules to reduce the risk and use of pesticides in the EU*. URL: https://ec.europa.eu/commission/presscorner/detail/en/QANDA_22_3694

European Commission (2022g): *Proposed CAP Strategic Plans and Commission observations. Summary overview for 27 Member States*. European Commission, Directorate-General for Agriculture and Rural Development. URL: https://agriculture.ec.europa.eu/system/files/2022-07/csp-overview-28-plans-overview-june-2022_en.pdf

European Commission (2023a): *Approved 28 CAP Strategic Plans (2023-2027): Summary overview for 27 Member States. Facts and figures*. European Commission, Directorate-General for Agriculture and Rural Development. URL: https://agriculture.ec.europa.eu/document/download/7b3a0485-c335-4e1b-a53a-9fe3733ca48f_en

European Commission (2023b): *Commission Staff Working Document: Drivers of food security. SWD(2023) 4 final*. URL: https://commission.europa.eu/document/download/3e370f0d-fabb-4614-bc98-73caac5b5215_en

European Commission (2023c): *Commission Staff Working Document Impact Assessment Report. Accompanying the document Directive of the European Parliament and of the Council amending Directive 2008/98/EC on waste. SWD(2023) 421 PART 1/4*. URL: https://environment.ec.europa.eu/system/files/2023-07/IMPACT%20ASSESSMENT%20REPORT_SWD_2023_421_part1_0.pdf

European Commission (2023d): *Communication. EU wide assessment of the draft updated National Energy and Climate Plans: An important step towards the more ambitious 2030 energy and climate objectives under the European Green Deal and RePowerEU. COM(2023) 796 final*. URL: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2023%3A796%3AFIN

European Commission (2023e): *Food-based dietary guidelines in Europe: Source documents*. URL: https://knowledge4policy.ec.europa.eu/health-promotion-knowledge-gateway/food-based-dietary-guidelines-europe-source-documents-food_en

European Commission (2023f): *Joint meeting of the EU platform on food losses and food waste and of the advisory group on sustainability of food systems. Summary report*. URL: https://food.ec.europa.eu/safety/food-waste/eu-actions-against-food-waste/eu-platform-food-losses-and-food-waste/platform-meetings_en

European Commission (2023g): *Promotion of EU farm products*. URL: https://agriculture.ec.europa.eu/common-agricultural-policy/market-measures/promotion-eu-farm-products_en#interimreport

European Commission (2023h): *Proposal for a Directive of the European Parliament and of the Council amending Directive 2008/98/EC on waste. 5 July 2023. COM(2023) 420 final*. URL: https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52023PC0420

European Commission (2023i): *Proposal for a Regulation of the European Parliament and of the Council on plants obtained by certain new genomic techniques and their food and feed, and amending Regulation (EU) 2017/625. COM(2023) 411 final*. URL: https://food.ec.europa.eu/document/download/c03805a6-4dcc-42ce-959c-e4d609010fa3_en

European Commission (2023j): *Proposal for a Regulation of the European Parliament and of the Council on the protection of animals during transport and related operations, amending Council Regulation (EC) No 1255/97 and repealing Council Regulation (EC) No 1/2005. COM(2023) 770 final*. URL: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2023%3A770%3AFIN

European Commission (2023k): *Report from the Commission on the functioning of the European carbon market in 2022 pursuant to Articles 10(5) and 21(2) of Directive 2003/87/EC. COM(2023) 654 final*. URL: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2023%3A654%3AFIN

European Commission (2023l): *Short-term outlook report for EU agricultural markets*. URL: https://agridata.ec.europa.eu/extensions/DashboardSTO/STO_Meat.html

European Commission (2023m): *State of the Energy Union Report 2023*. URL: https://eur-lex.europa.eu/resource.html?uri=cellar:b27b8b93-725d-11ee-9220-01aa75ed71a1.0001.02/DOC_1&format=PDF

European Commission (2023n): *State of the Union Address by President von der Leyen*. URL: https://ec.europa.eu/commission/presscorner/detail/en/speech_23_4426

European Commission (2023o): *Summary of CAP Strategic Plans for 2023-2027: Joint effort and collective ambition*. URL: https://agriculture.ec.europa.eu/cap-my-country/cap-strategic-plans_en

European Commission (2024a): *Certification of permanent carbon removals, carbon farming and carbon storage in products*. URL: https://climate.ec.europa.eu/eu-action/certification-permanent-carbon-removals-carbon-farming-and-carbon-storage-products/certification-permanent-carbon-removals-carbon-farming-and-carbon-storage-products_en

European Commission (2024b): *Commission Staff Working Document Impact Assessment Report. Securing our future: Europe's 2040 climate target and path to climate neutrality by 2050 building a sustainable, just and prosperous society*. URL: https://climate.ec.europa.eu/document/download/768bc81f-5f48-48e3-b4d4-e02ba09faca1_en

European Commission (2024c): *Common agricultural policy funds*. URL: https://agriculture.ec.europa.eu/common-agricultural-policy/financing-cap/cap-funds_en

European Commission (2024d): *Communication. Building the future with nature: Boosting biotechnology and biomanufacturing in the EU. COM(2024) 137 final*. URL: https://eur-lex.europa.eu/legal-content/DE/ALL/?uri=COM:2024:0137:FIN

European Commission (2024e): *Conditionality*. URL: https://agriculture.ec.europa.eu/common-agricultural-policy/income-support/conditionality_en

European Commission (2024f): *Eligibility for direct payments of the Common Agricultural Policy 2023–2027*. URL: https://agriculture.ec.europa.eu/document/download/66f112fe-8281-4366-a377-9e86d6e9bb71_en

European Commission (2024g): *Interactive innovation and the EIP-AGRI*. URL: https://research-and-innovation.ec.europa.eu/research-area/agriculture-forestry-and-rural-areas/interactive-innovation-and-eip-agri_en

European Commission (2024h): *Memo on the Commission's package of support to EU farmers*. URL: https://ec.europa.eu/commission/presscorner/detail/en/QANDA_24_1494

European Commission (2024i): *Ninth Report on Economic, Social and Territorial Cohesion*. URL: https://ec.europa.eu/regional_policy/information-sources/cohesion-report_en

European Commission (2024j): *Number of laying hens by farming method*. URL: https://agriculture.ec.europa.eu/document/download/9bdf9842-1eb6-41a2-8845-49738b812b2b_en

European Commission (2024k): *Proposal for a Regulation of the European Parliament and of the Council amending Regulations (EU) 2021/2115 and (EU) 2021/2116 as regards good agricultural and environmental condition standards, schemes for climate, environment and animal welfare, amendments to CAP Strategic Plans, review of CAP Strategic Plans and exemptions from controls and penalties. COM(2024) 139 final*. URL: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52024PC0139

European Commission (2024l): *Result Indicators dashboard*. URL: https://agridata.ec.europa.eu/extensions/DashboardCapPlan/result_indicators.html

European Commission (2024m): *The long-term vision for the EU's rural areas: Key achievements and ways forward. COM(2024) 450 final*. URL: https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=comnat:COM_2024_0450_FIN

European Commission & EIB (European Investment Bank) (2023): *Survey on financial needs and access to finance of EU agri-food micro, small and medium-sized enterprises.* URL: https://www.fi-compass.eu/library/market-analysis/survey-financial-needs-and-access-finance-eu-agri-food-micro-small-and

European Commission & Group of Chief Scientific Advisors (2020): *Towards a sustainable food system: Moving from food as a commodity to food as more of a common good. Independent expert report.* Scientific Opinion 8. European Commission, Directorate-General for Research and Innovation. URL: https://scientificadvice.eu/advice/a-sustainable-food-system-for-the-european-union/

European Commission & Group of Chief Scientific Advisors (2023): *Towards sustainable food consumption: Promoting healthy, affordable and sustainable food consumption choices.* Scientific Opinion 14. European Commission, Directorate-General for Research and Innovation. URL: https://data.europa.eu/doi/10.2777/29369

European Commission & JRC (Joint Research Centre) (2023): *iMAP, Integrated Modelling platform for Agro-economic and resource Policy analysis: Tools to assess MS CAP strategic plans on environment and climate performance*. URL: https://wikis.ec.europa.eu/display/IMAP/IMAP+Home+page

European Commission, JRC (Joint Research Centre), Paganos, P. & De Rosa, D. (2023): *Indicators to support the soil perspectives of the Common Agricultural Policy (CAP)*. URL: https://data.europa.eu/doi/10.2760/235604

European Commission, Scheele, M., Hart, K. & Baldock, D. (2010): *Public goods and public intervention in agriculture*. European Commission, Directorate-General for Agriculture and Rural Development. URL: https://data.europa.eu/doi/10.2762/21600

European Parliament (2022): *Texts adopted—A long-term vision for the EU's rural areas—Tuesday, 13 December 2022*. URL: https://www.europarl.europa.eu/doceo/document/TA-9-2022-0436_EN.html

European Parliament (2023a): *European Protein Strategy (2023/2015(INI)). European Parliament resolution of 19 October 2023*. URL: https://www.europarl.europa.eu/doceo/document/TA-9-2023-0375_EN.html

European Parliament (2023b): *Financing of the CAP: Facts and figures*. URL: https://www.europarl.europa.eu/factsheets/en/sheet/106/financing-of-the-cap-facts-and-figures

European Union (2012): *Charter of Fundamental Rights of the European Union*. URL: https://data.europa.eu/eli/treaty/char_2012/oj/eng

European Union (2021): *European Child Guarantee. Council Recommendation (EU) 2021/1004 of 14 July 2021 establishing a European Child Guarantee*. URL: https://ec.europa.eu/social/main.jsp?catId=1428&langId=en

European Union (2022): *European Union Methane Action Plan*. URL: https://energy.ec.europa.eu/document/download/f9a49150-903e-46a6-aec7-f2c21272e9e0_en

European Union (2023a): *Attitudes of Europeans towards animal welfare: Special Eurobarometer 533*. URL: https://europa.eu/eurobarometer/surveys/detail/2996

European Union (2023b): *European Union. 2023 Common Reporting Format (CRF) Table. UNFCCC*. URL: https://unfccc.int/documents/627830

Eurostat (2009): *Key variables by legal status of holding, size of farm (UAA) and NUTS-2 regions*. URL: https://ec.europa.eu/eurostat/databrowser/view/ef_ov_kvaa__custom_12265404/default/table

Eurostat (2017): *Key farm variables: Area, livestock (LSU), labour force and standard output (SO) by agricultural size of farm (UAA), legal status of holding and NUTS-2 regions*. URL: https://ec.europa.eu/eurostat/databrowser/view/ef_kvaareg__custom_12265305/default/table

Eurostat (2019): *The fruit and vegetable sector in the EU: A statistical overview*. URL: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=The_fruit_and_vegetable_sector_in_the_EU_-_a_statistical_overview

Eurostat (2020): *Agriculture, forestry and fishery statistics. 2020 edition*. URL: https://ec.europa.eu/eurostat/web/products-statistical-books/-/ks-fk-20-001

Eurostat (2021): *Land use statistics*. URL: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Land_use_statistics

Eurostat (2022a): *Key figures on the European food chain. 2022 edition*. URL: https://ec.europa.eu/eurostat/web/products-key-figures/w/ks-fk-22-001

Eurostat (2022b): *Urban-rural Europe: Introduction*. URL: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Urban-rural_Europe_-_introduction

Eurostat (2023a): *Agri-environmental indicator: Livestock patterns*. URL: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Agri-environmental_indicator_-_livestock_patterns

Eurostat (2023b): *Food waste and food waste prevention – estimates*. URL: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Food_waste_and_food_waste_prevention_-_estimates

Eurostat (2023c): *Forests, forestry and logging*. URL: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Forests,_forestry_and_logging

Eurostat (2023d): *How much do households spend on food and alcohol?* URL: https://ec.europa.eu/eurostat/web/products-eurostat-news/w/ddn-20230201-1

Eurostat (2023e): *Key figures on the European food chain. 2023 edition*. URL: https://ec.europa.eu/eurostat/web/products-key-figures/w/key-figures-on-the-european-food-chain-2023-edition

Eurostat (2023f): *Livestock unit (LSU)*. URL: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Livestock_unit_(LSU)

Eurostat (2023g): *Performance of the agricultural sector*. URL: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Performance_of_the_agricultural_sector

Eurostat (2023h): *Wood products: Production and trade*. URL: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Wood_products_-_production_and_trade

Eurostat (2024a): *Employment (thousand persons) by NUTS-3 regions*. URL: https://ec.europa.eu/eurostat/databrowser/view/nama_10r_3empers__custom_11466110/default/table?lang=en

Eurostat (2024b): *Farm indicators by legal status of the holding, utilised agricultural area (UUA), type and economic size of the farm and NUTS-2 region*. URL: https://ec.europa.eu/eurostat/databrowser/view/ef_m_farmleg__custom_11497480/default/table

Eurostat (2024c): *Gross value added at basic prices by NUTS-3 regions*. URL: https://ec.europa.eu/eurostat/databrowser/view/nama_10r_3gva__custom_11465595/default/table?lang=en

Eurostat (2024d): *Inability to afford a meal with meat, chicken, fish (or vegetarian equivalent) every second day. EU-SILC survey 2022*. URL: https://ec.europa.eu/eurostat/databrowser/view/ilc_mdes03/default/table?lang=en

Expert Group for a Green Tax Reform (2024): *Green tax reform: Final report*. URL: https://skm.dk/media/tngh1b4r/green-tax-reform-final-report.pdf

Fader, M., Shi, S., von Bloh, W., Bondeau, A. & Cramer, W. (2016): Mediterranean irrigation under climate change: More efficient irrigation needed to compensate for increases in irrigation water requirements. *Hydrology and Earth System Sciences*, *20*(2), 953–973. URL: https://doi.org/10.5194/hess-20-953-2016

Fahrig, L., Baudry, J., Brotons, L., Burel, F. G., Crist, T. O., Fuller, R. J., Sirami, C., Siriwardena, G. M. & Martin, J.-L. (2011): Functional landscape heterogeneity and animal biodiversity in agricultural landscapes. *Ecology Letters*, *14*(2), 101–112. URL: https://doi.org/10.1111/j.1461-0248.2010.01559.x

Fanzo, J., Haddad, L., Schneider, K. R., Béné, C., Covic, N. M., Guarin, A., Herforth, A. W., Herrero, M., Sumaila, U. R., Aburto, N. J., Amuyunzu-Nyamongo, M., Barquera, S., Battersby, J., Beal, T., Bizzotto Molina, P., Brusset, E., Cafiero, C., Campeau, C., Caron, P., … Rosero Moncayo, J. (2021): Viewpoint: Rigorous monitoring is necessary to guide food system transformation in the countdown to the 2030 global goals. *Food Policy*, *104*, 102163. URL: https://doi.org/10.1016/j.foodpol.2021.102163

FAO (Food and Agriculture Organization of the United Nations) (2018): *Sustainable Food Systems: Concept and Framework. Policy support and governance*. URL: https://www.fao.org/policy-support/tools-and-publications/resources-details/en/c/1160811/

FAO (Food and Agriculture Organization of the United Nations) (2021): *The need for guidance on alternative proteins highlighted to Codex Alimentarius Commission*. URL: https://www.fao.org/in-action/sustainable-and-circular-bioeconomy/resources/news/details/ru/c/1459357/

FAO (Food and Agriculture Organization of the United Nations) (2023a): *Contribution of terrestrial animal source food to healthy diets for improved nutrition and health outcomes: An evidence and policy overview on the state of knowledge and gaps*. URL: https://doi.org/10.4060/cc3912en

FAO (Food and Agriculture Organization of the United Nations) (2023b): *Pathways towards lower emissions: A global assessment of the greenhouse gas emissions and mitigation options from livestock agrifood systems*. URL: https://doi.org/10.4060/cc9029en

FAO, IFAD, UNICEF, WFP & WHO (Food and Agriculture Organization of the United Nations, International Fund for Agricultural Development, United Nations Children's Fund, World Food Programme & World Health Organization) (2023): *The State of Food Security and Nutrition in the World 2023: Urbanization, agrifood systems transformation and healthy diets across the rural–urban continuum.* URL: https://doi.org/10.4060/cc3017en

Felix, L., Houet, T. & Verburg, P. H. (2022): Mapping biodiversity and ecosystem service trade-offs and synergies of agricultural change trajectories in Europe. *Environmental Science & Policy*, *136*, 387–399. URL: https://doi.org/10.1016/j.envsci.2022.07.004

Ferrante, M., Schulze, M. & Westphal, C. (2024): Hedgerows can increase predation rates in wheat fields in homogeneous agricultural landscapes. *Journal of Environmental Management*, *349*. URL: https://doi.org/10.1016/j.jenvman.2023.119498

Finck, P., Riecken, U. & Schröder, E. (2002): Pasture landscapes and nature conservation: New strategies for the preservation of open landscapes in Europe. In: B. Redecker, W. Härdtle, P. Finck, U. Riecken & E. Schröder (Eds.), *Pasture Landscapes and Nature Conservation*, 1–13. URL: https://doi.org/10.1007/978-3-642-55953-2_1

Finger, R. (2016): Assessment of uncertain returns from investment in short rotation coppice using risk adjusted discount rates. *Biomass and Bioenergy*, *85*, 320–326. URL: https://doi.org/10.1016/j.biombioe.2015.12.028

Finger, R. (2023): Digital innovations for sustainable and resilient agricultural systems. *European Review of Agricultural Economics*, *50*(4), 1277–1309. URL: https://doi.org/10.1093/erae/jbad021

Flachowsky, G., Meyer, U. & Südekum, K.-H. (2017): Land use for edible protein of animal origin: A review. *Animals*, *7*(3), 25. URL: https://doi.org/10.3390/ani7030025

Flanagan, K., Robertson, K. & Hanson, C. (2019): *Reducing Food Loss and Waste: Setting a Global Action Agenda*. WRI, World Resources Institute. URL: https://www.wri.org/research/reducing-food-loss-and-waste-setting-global-action-agenda

Flechard, C. R., Van Oijen, M., Cameron, D. R., de Vries, W., Ibrom, A., Buchmann, N., Dise, N. B., Janssens, I. A., Neirynck, J., Montagnani, L., Varlagin, A., Loustau, D., Legout, A., Ziemblińska, K., Aubinet, M., Aurela, M., Chojnicki, B. H., Drewer, J., Eugster, W., … Sutton, M. A. (2020): Carbon-nitrogen interactions in European forests and semi-natural vegetation – Part 2: Untangling climatic, edaphic, management and nitrogen deposition effects on carbon sequestration potentials. *Biogeosciences, 17*(6), 1621–1654. URL: https://doi.org/10.5194/bg-17-1621-2020

Ford, J. S., Bale, C. S. E. & Taylor, P. G. (2024): The factors determining uptake of energy crop cultivation and woodland creation in England: Insights from farmers and landowners. *Biomass and Bioenergy*, *180*, 107021. URL: https://doi.org/10.1016/j.biombioe.2023.107021

Forest Europe (2020): *State of Europe's Forests 2020*. Ministerial Conference on the Protection of Forests in Europe. URL: https://foresteurope.org/state-of-europes-forests/

Fraga, H., Moriondo, M., Leolini, L. & Santos, J. A. (2021): Mediterranean olive orchards under climate change: A review of future impacts and adaptation strategies. *Agronomy*, *11*(1), 56. URL: https://doi.org/10.3390/agronomy11010056

Frankowska, A., Jeswani, H. K. & Azapagic, A. (2019): Environmental impacts of vegetables consumption in the UK. *Science of The Total Environment*, *682*, 80–105. URL: https://doi.org/10.1016/j.scitotenv.2019.04.424

Frisvold, G. B. (2019): How low can you go? Estimating impacts of reduced pesticide use. *Pest Management Science*, *75*(5), 1223–1233. URL: https://doi.org/10.1002/ps.5249

Gámez-Virués, S., Perović, D. J., Gossner, M. M., Börschig, C., Blüthgen, N., de Jong, H., Simons, N. K., Klein, A.-M., Krauss, J., Maier, G., Scherber, C., Steckel, J., Rothenwöhrer, C., Steffan-Dewenter, I., Weiner, C. N., Weisser, W., Werner, M., Tscharntke, T. & Westphal, C. (2015): Landscape simplification filters species traits and drives biotic homogenization. *Nature Communications*, *6*(1), 8568. URL: https://doi.org/10.1038/ncomms9568

García-Vega, D., Dumas, P., Prudhomme, R., Kremen, C. & Aubert, P.-M. (2024): A safe agricultural space for biodiversity. *Frontiers in Sustainable Food Systems*, *8*. URL: https://www.frontiersin.org/articles/10.3389/fsufs.2024.1328800

Garibaldi, L. A., Oddi, F. J., Miguez, F. E., Bartomeus, I., Orr, M. C., Jobbágy, E. G., Kremen, C., Schulte, L. A., Hughes, A. C., Bagnato, C., Abramson, G., Bridgewater, P., Carella, D. G., Díaz, S., Dicks, L. V., Ellis, E. C., Goldenberg, M., Huaylla, C. A., Kuperman, M., … Zhu, C. (2021): Working landscapes need at least 20% native habitat. *Conservation Letters*, *14*(2). URL: https://doi.org/10.1111/conl.12773

Garibaldi, L. A., Zermoglio, P. F., Jobbágy, E. G., Andreoni, L., Ortiz de Urbina, A., Grass, I. & Oddi, F. J. (2023): How to design multifunctional landscapes? *Journal of Applied Ecology*, *60*(12). URL: https://doi.org/10.1111/1365-2664.14517

Garske, B., Bau, A. & Ekardt, F. (2021): Digitalization and AI in European agriculture: A strategy for achieving climate and biodiversity targets? *Sustainability*, *13*(9). URL: https://doi.org/10.3390/su13094652

Gautam, H. R., Bhardwaj, M. L. & Kumar, R. (2013): Climate change and its impact on plant diseases. *Current Science*, *105*(12), 1685–1691. URL: https://www.jstor.org/stable/24099750

Geiger, F., Bengtsson, J., Berendse, F., Weisser, W. W., Emmerson, M., Morales, M. B., Ceryngier, P., Liira, J., Tscharntke, T., Winqvist, C., Eggers, S., Bommarco, R., Pärt, T., Bretagnolle, V., Plantegenest, M., Clement, L. W., Dennis, C., Palmer, C., Oñate, J. J., … Inchausti, P. (2010): Persistent negative effects of pesticides on biodiversity and biological control potential on European farmland. *Basic and Applied Ecology*, *11*(2), 97–105. URL: https://doi.org/10.1016/j.baae.2009.12.001

Gertel, J. & Sippel, S. R. (2014): *Seasonal Workers in Mediterranean Agriculture: The Social Costs of Eating Fresh*. URL: https://www.routledge.com/Seasonal-Workers-in-Mediterranean-Agriculture-The-Social-Costs-of-Eating-Fresh/Gertel-Sippel/p/book/9781138097193

Giannakis, E. & Bruggeman, A. (2015): The highly variable economic performance of European agriculture. *Land Use Policy*, *45*, 26–35. URL: https://doi.org/10.1016/j.landusepol.2014.12.009

GMC (Greifswald Mire Centre) (2022a): *Informationspapier des Greifswald Moor Centrum zu Photovoltaik-Anlagen auf Moorböden*. März 2022. URL: https://www.greifswaldmoor.de/files/dokumente/Infopapiere_Briefings/Positionspapier_PV-auf-Moor_fin.pdf

GMC (Greifswald Mire Centre) (2022b): *The Global Peatland Database*. URL: https://greifswaldmoor.de/global-peatland-database-en.html

GMC (Greifswald Mire Centre) & Wetlands International (2021): *Opportunities for Peatlands and Paludiculture in the EU Common Agricultural Policy (2023-2027): Recommendations for EU Member States for their CAP Strategic Plans*. URL: https://www.greifswaldmoor.de/files/dokumente/Infopapiere_Briefings/202111_Opportunities-for-paludiculture-in-CAP-1.pdf

GMC (Greifswald Mire Centre) & Wetlands International (2022): *WaterLANDS. Higher ambition for Peatlands in the EU Nature Restoration Law Proposal*. Policy briefing. URL: https://cdn.sanity.io/files/34jdpbeg/production/7dd1e602fec7d271269f42312a1bc525e095750f.pdf

Godde, C. M., Mason-D'Croz, D., Mayberry, D. E., Thornton, P. K. & Herrero, M. (2021): Impacts of climate change on the livestock food supply chain: A review of the evidence. *Global Food Security*, *28*, 100488. URL: https://doi.org/10.1016/j.gfs.2020.100488

Goldman, R. L., Thompson, B. H. & Daily, G. C. (2007): Institutional incentives for managing the landscape: Inducing cooperation for the production of ecosystem services. *Ecological Economics*, *64*(2), 333–343. URL: https://doi.org/10.1016/j.ecolecon.2007.01.012

González-Domínguez, E., Caffi, T., Rossi, V., Salotti, I. & Fedele, G. (2023): Plant disease models and forecasting: Changes in principles and applications over the last 50 years. *Phytopathology*, *113*(4), 678–693. URL: https://doi.org/10.1094/PHYTO-10-22-0362-KD

Gorton, M., Yeh, C.-H., Chatzopoulou, E., White, J., Tocco, B., Hubbard, C. & Hallam, F. (2023): Consumers' willingness to pay for an animal welfare food label. *Ecological Economics*, *209*, 107852. URL: https://doi.org/10.1016/j.ecolecon.2023.107852

Grass, I., Batáry, P. & Tscharntke, T. (2021): Combining land-sparing and land-sharing in European landscapes. In: D. A. Bohan & A. J. Vanbergen (Eds.), *Future of Agricultural Landscapes*, 251–303. URL: https://doi.org/10.1016/bs.aecr.2020.09.002

Grassi, G., Fiorese, G., Pilli, R., Jonsson, K., Blujdea, V., Korosuo, A. & Vizzarri, M. (2021): *Brief on the role of the forest-based bioeconomy in mitigating climate change through carbon storage and material substitution.* JRC124374. European Commission. URL: https://publications.jrc.ec.europa.eu/repository/handle/JRC124374

Grethe, H. (2017): The economics of farm animal welfare. *Annual Review of Resource Economics, 9,* 75–94. URL: https://doi.org/10.1146/annurev-resource-100516-053419

Grethe, H. & Chemnitz, C. (2023): *The EU's Common Agricultural Policy from 2028 onwards: Impulse Paper on the Design of the EU Framework*. URL: https://www.agrar.hu-berlin.de/en/institut-en/departments/daoe/ihe-en/publ/the-gap-from-2028-onwards.pdf

Grethe, H., Martinez, J., Osterburg, B., Taube, F. & Thom, F. (2021): *Klimaschutz im Agrar- und Ernährungssystem Deutschlands: Die drei zentralen Handlungsfelder auf dem Weg zur Klimaneutralität*. Stiftung Klimaneutralität. URL: https://www.stiftung-klima.de/app/uploads/2021/06/2021-06-01-Klimaneutralitaet_Landwirtschaft.pdf

Grodkowski, G., Gołębiewski, M., Slósarz, J., Grodkowska, K., Kostusiak, P., Sakowski, T. & Puppel, K. (2023): Organic milk production and dairy farming constraints and prospects under the laws of the European Union. *Animals*, *13*(9), 1457. URL: https://doi.org/10.3390/ani13091457

Günther, A., Barthelmes, A., Huth, V., Joosten, H., Jurasinski, G., Koebsch, F. & Couwenberg, J. (2020): Prompt rewetting of drained peatlands reduces climate warming despite methane emissions. *Nature Communications*, *11*(1). URL: https://doi.org/10.1038/s41467-020-15499-z

Guyomard, H., Détang-Dessendre, C., Dupraz, P., Delaby, L., Huyghe, C., Peyraud, J.-L., Reboud, X. & Sirami, C. (2023): How the Green Architecture of the 2023–2027 Common Agricultural Policy could have been greener. *Ambio*, *52*(8), 1327–1338. URL: https://doi.org/10.1007/s13280-023-01861-0

Hackfort, S. (2023): Unlocking sustainability? The power of corporate lock-ins and how they shape digital agriculture in Germany. *Journal of Rural Studies*, *101*. URL: https://doi.org/10.1016/j.jrurstud.2023.103065

Hall, K. D. (2018): Did the food environment cause the obesity epidemic? *Obesity (Silver Spring, Md.)*, *26*(1), 11–13. URL: https://doi.org/10.1002/oby.22073

Hamelin, L., Wesnaes, M., Wenzel, H. & Petersen, B. (2011): Environmental consequences of future biogas technologies based on separated slurry. *Environmental Science & Technology*, *45*, 5869–5877. URL: https://doi.org/10.1021/es200273j

Hart, K. (2024): *Securing greater environmental and climate performance from EU agricultural funds*. IEEP, Institute for European Environmental Policy. URL: https://ieep.eu/publications/securing-greater-environmental-and-climate-performance-from-eu-agricultural-funds/

Hass, A. L., Kormann, U. G., Tscharntke, T., Clough, Y., Baillod, A. B., Sirami, C., Fahrig, L., Martin, J.-L., Baudry, J., Bertrand, C., Bosch, J., Brotons, L., Burel, F., Georges, R., Giralt, D., Marcos-García, M. Á., Ricarte, A., Siriwardena, G. & Batáry, P. (2018): *Landscape configurational heterogeneity by small-scale agriculture, not crop diversity, maintains pollinators and plant reproduction in Western Europe. Proceedings. Biological Sciences, 285.* URL: https://doi.org/10.1098/rspb.2017.2242

Hauk, S., Knoke, T. & Wittkopf, S. (2014): Economic evaluation of short rotation coppice systems for energy from biomass: A review. *Renewable and Sustainable Energy Reviews*, *29*, 435–448. URL: https://doi.org/10.1016/j.rser.2013.08.103

Hawkes, C., Walton, S., Haddad, L. & Fanzo, J. (2020): *42 Policies and actions to orient food systems towards healthier diets for all*. URL: https://www.foodsystemsdashboard.org/resources/publication-42.pdf

Heinemann, F. (2017): *The Case for Co-Financing the CAP.* EconPol Working Paper 4. URL: https://www.econpol.eu/publications/working_paper_4

Helepciuc, F.-E. & Todor, A. (2022): Greener European agriculture? Evaluating EU Member States' transition efforts to integrated pest management through their National Action Plans. *Agronomy*, *12*(10). URL: https://doi.org/10.3390/agronomy12102438

Hempel, S., Menz, C., Pinto, S., Galán, E., Janke, D., Estellés, F., Müschner-Siemens, T., Wang, X., Heinicke, J., Zhang, G., Amon, B., del Prado, A. & Amon, T. (2019): Heat stress risk in European dairy cattle husbandry under different climate change scenarios: Uncertainties and potential impacts. *Earth System Dynamics*, *10*(4), 859–884. URL: https://doi.org/10.5194/esd-10-859-2019

Henning, C. & Witzke, P. (2021): *Economic and Environmental impacts of the Green Deal on the Agricultural Economy: A Simulation Study of the Impact of the F2F-Strategy on Production, Trade, Welfare and the Environment based on the CAPRI-Mode. Executive Summary.* URL: https://www.fediol.eu/data/Farm_to_fork_Studie_Executive_Summary_EN.pdf

Herforth, A. & Ahmed, S. (2015): The food environment, its effects on dietary consumption, and potential for measurement within agriculture-nutrition interventions. *Food Security*, *7*(3), 505–520. URL: https://doi.org/10.1007/s12571-015-0455-8

Hering, D., Schürings, C., Wenskus, F., Blackstock, K., Borja, A., Birk, S., Bullock, C., Carvalho, L., Dagher-Kharrat, M. B., Lakner, S., Lovrić, N., McGuinness, S., Nabuurs, G.-J., Sánchez-Arcilla, A., Settele, J. & Pe'er, G. (2023): Securing success for the Nature Restoration Law. *Science*, *382*(6676), 1248–1250. URL: https://doi.org/10.1126/science.adk1658

Herrero, E., Teresa, M. & Bescós, B. (2015): *LIFE + MANEV: Evaluation of Manure Management Systems and Treatment Technologies in Europe*.

Herzberg, R., Schmidt, T. & Keck, M. (2022): Market power and food loss at the producer-retailer interface of fruit and vegetable supply chains in Germany. *Sustainability Science*, *17*(6), 2253–2267. URL: https://doi.org/10.1007/s11625-021-01083-x

Hickler, T., Vohland, K., Feehan, J., Miller, P. A., Smith, B., Costa, L., Giesecke, T., Fronzek, S., Carter, T. R., Cramer, W., Kühn, I. & Sykes, M. T. (2012): Projecting the future distribution of European potential natural vegetation zones with a generalized, tree species-based dynamic vegetation model. *Global Ecology and Biogeography*, *21*(1), 50–63. URL: https://doi.org/10.1111/j.1466-8238.2010.00613.x

Hilhorst, M. A., Melse, R. W., Willers, H. C., Groenestein, C. M. & Monteny, G. J. (2002): *Reduction of Methane Emissions from Manure*. URL: https://edepot.wur.nl/303610

Hill, B. & Bradley, B. D. (2015): *Comparison of Farmers' Incomes in the EU Member States*. European Parliament, Policy Department for Structural and Cohesion Policies. URL: https://www.europarl.europa.eu/thinktank/en/document/IPOL_STU(2015)540374

Hinze, J., Albrecht, A. & Michiels, H.-G. (2023): Climate-adapted potential vegetation: A European multiclass model estimating the future potential of natural vegetation. *Forests*, *14*(2), 239. URL: https://doi.org/10.3390/f14020239

Hirschelmann, S., Abel, S. & Krabbe, K. (2023): *Hemmnisse und Lösungsansätze für beschleunigte Planung und Genehmigung von Moorklimaschutz: Ergebnisse einer Bestandsaufnahme in den moorreichen Bundesländern*. Greifswald Moor Centrum-Schriftenreihe 01/2023. URL: https://www.greifswaldmoor.de/files/dokumente/GMC%20Schriften/2023-01_Hirschelmann%20et%20al_Beschleunigte%20Planung%20und%20Genehmigung%20von%20Moorklimaschutz_korr.pdf

Hirschelmann, S., Tanneberger, F., Wichmann, S., Reichelt, F., Hohlbein, M., Couwenberg, J., Busse, S., Schröder, C. & Nordt, A. (2020): *Moore in Mecklenburg-Vorpommern im Kontext nationaler und internationaler Klimaschutzziele—Zustand und Entwicklungspotenzial. Faktensammlung*. Greifswald Moor Centrum-Schriftenreihe 03/2020. URL: https://greifswaldmoor.de/files/dokumente/GMC%20Schriften/2020-03_Moore%20in%20MV_Faktensammlung_%20Hirschelmann%20et%20al_final.pdf

HLPE (High Level Panel of Experts on Food Security and Nutrition) (2017): *Nutrition and Food Systems: A Report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security*. URL: https://www.fao.org/policy-support/tools-and-publications/resources-details/en/c/1155796/

HLPE (High Level Panel of Experts on Food Security and Nutrition) (2020): *Food Security and Nutrition: Building a Global Narrative towards 2030: A Report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security*. URL: https://www.fao.org/cfs/cfs-hlpe/publications/hlpe-15/en

Hoang, A. T., Goldfarb, J. L., Foley, A. M., Lichtfouse, E., Kumar, M., Xiao, L., Ahmed, S. F., Said, Z., Luque, R., Bui, V. G. & Nguyen, X. P. (2022): Production of biochar from crop residues and its application for anaerobic digestion. *Bioresource Technology*, *363*. URL: https://doi.org/10.1016/j.biortech.2022.127970

Hofer & Pautz GbR & DUENE e. V. (2024): *Potenzialstudie „Moore in Niedersachsen"*. Niedersächsisches Ministerium für Umwelt, Energie und Klimaschutz. URL: https://www.umwelt.niedersachsen.de/startseite/themen/moorschutz/ergebnisse-der-potenzialstudie-moore-in-niedersachsen-232691.html

Hofreither, M (2013): 'Progressive cofinancing' of CAP direct payments. Matching domestic preferences with common pools. *Journal of Agricultural Science and Applications*, *2*(4), 219–225. URL: https://www.cabidigitallibrary.org/doi/epdf/10.5555/20143145941

Hofstetter, P., Frey, H.-J., Gazzarin, C., Wyss, U. & Kunz, P. (2014): Dairy farming: Indoor v. pasture-based feeding. *The Journal of Agricultural Science*, *152*(6), 994–1011. URL: https://doi.org/10.1017/S0021859614000227

Holland, J. M. (2004): The environmental consequences of adopting conservation tillage in Europe: Reviewing the evidence. *Agriculture, Ecosystems & Environment*, *103*(1), 1–25. URL: https://doi.org/10.1016/j.agee.2003.12.018

Holtkamp, F., Clemens, J. & Trimborn, M. (2023): Calcium cyanamide reduces methane and other trace gases during long-term storage of dairy cattle and fattening pig slurry. *Waste Management*, *161*, 61–71. URL: https://doi.org/10.1016/j.wasman.2023.02.018

Holzwarth, S., Thonfeld, F., Abdullahi, S., Asam, S., Da Ponte Canova, E., Gessner, U., Huth, J., Kraus, T., Leutner, B. & Kuenzer, C. (2020): Earth observation based monitoring of forests in Germany: A review. *Remote Sensing*, *12*(21), 3570. URL: https://doi.org/10.3390/rs12213570

Hossard, L., Philibert, A., Bertrand, M., Colnenne-David, C., Debaeke, P., Munier-Jolain, N., Jeuffroy, M. H., Richard, G. & Makowski, D. (2014): Effects of halving pesticide use on wheat production. *Scientific Reports*, *4*(1), 4405. URL: https://doi.org/10.1038/srep04405

Howard, C., Dymond, C. C., Griess, V. C., Tolkien-Spurr, D. & Van Kooten, G. C. (2021): Wood product carbon substitution benefits: A critical review of assumptions. *Carbon Balance and Management*, *16*(1), 9. URL: https://doi.org/10.1186/s13021-021-00171-w

Humpenöder, F., Bodirsky, B. L., Weindl, I., Lotze-Campen, H., Linder, T. & Popp, A. (2022): Projected environmental benefits of replacing beef with microbial protein. *Nature*, *605,* 60–96. URL: https://doi.org/10.1038/s41586-022-04629-w

IASS (Institute for Advanced Sustainability Studies) (2022): *Kann der Speiseplan die Erde retten? Fünf Aktionsvorschläge zur Beschleunigung einer kommunalen Ernährungswende*. URL: https://publications.iass-potsdam.de/rest/items/item_6002413_5/component/file_6002440/content

Ibidhi, R. & Calsamiglia, S. (2020): Carbon footprint ssessment of Spanish dairy cattle farms: Effectiveness of dietary and farm management practices as a mitigation strategy. *Animals*, *10*(11), 2083. URL: https://doi.org/10.3390/ani10112083

ICESCR (International Covenant on Economic, Social and Cultural Rights) (1976): *International Covenant on Economic, Social and Cultural Rights*. OHCHR, Office of the United Nations High Commissioner for Human Rights. URL: https://www.ohchr.org/en/instruments-mechanisms/instruments/international-covenant-economic-social-and-cultural-rights

ICRC (International Committee of the Red Cross) (1989): *Convention on the Rights of the Child*. OHCHR, Office of the United Nations High Commissioner for Human Rights. URL: https://www.ohchr.org/en/instruments-mechanisms/instruments/convention-rights-child

ILO (International Labour Organization) (n.d.): *Conventions and Protocols*. Retrieved 18 April 2024, from URL: https://www.ilo.org/dyn/normlex/en/f?p=NORMLEXPUB:12000:0::NO:::

Incrocci, L., Thompson, R. B., Fernandez-Fernandez, M. D., De Pascale, S., Pardossi, A., Stanghellini, C., Rouphael, Y. & Gallardo, M. (2020): Irrigation management of European greenhouse vegetable crops. *Agricultural Water Management*, *242*. URL: https://doi.org/10.1016/j.agwat.2020.106393

IPBES (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services) (2019): *Summary for Policymakers of the Global Assessment Report on Biodiversity and Ecosystem Services*. URL: https://doi.org/10.5281/zenodo.3553579

IPCC (Intergovernmental Panel on Climate Change) (2013): *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. URL: https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_all_final.pdf

IPCC (Intergovernmental Panel on Climate Change) (2014): *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands*. URL: https://www.ipcc.ch/publication/2013-supplement-to-the-2006-ipcc-guidelines-for-national-greenhouse-gas-inventories-wetlands/

IPCC (Intergovernmental Panel on Climate Change) (2018): *Global Warming of 1.5 °C: IPCC Special Report on Impacts of Global Warming of 1.5 °C above Pre-Industrial Levels in Context of Strengthening Response to Climate Change, Sustainable Development, and Efforts to Eradicate Poverty*. URL: https://doi.org/10.1017/9781009157940

IPCC (Intergovernmental Panel on Climate Change) (2019): *Special Report on Climate Change and Land*. URL: https://www.ipcc.ch/site/assets/uploads/sites/4/2022/11/SRCCL_Technical-Summary.pdf

IPCC (Intergovernmental Panel on Climate Change) (2021): *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. URL: https://doi.org/10.1017/9781009157896

IPCC (Intergovernmental Panel on Climate Change) (2023): *Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. URL: https://doi.org/10.59327/IPCC/AR6-9789291691647

Ippenberger, B. & Hofmann, G. (2022): *Tierwohl in der Milchviehhaltung: Zusätzlicher Kostenaufwand trifft kleinere (bayerische Anbinde-) Betriebe am härtesten*. LfL, Bayerische Landesanstalt für Landwirtschaft. URL: https://www.lfl.bayern.de/iba/tier/299320/index.php

Isermeyer, F., Heidecke, C. & Osterburg, B. (2019): *Integrating Agriculture into Carbon Pricing.* Thünen Working Paper 136a. URL: https://literatur.thuenen.de/digbib_extern/dn062987.pdf

IUCN (International Union for Conservation of Nature) (2020): *Guidelines for Conserving Connectivity through Ecological Networks and Corridors*. URL: https://portals.iucn.org/library/node/49061

Ivezić, V., Yu, Y. & Werf, W. van der. (2021): Crop yields in European agroforestry systems: A meta-analysis. *Frontiers in Sustainable Food Systems*, *5*. URL: https://doi.org/10.3389/fsufs.2021.606631

Jeangros, B. & Courvoisier, N. (2019): *Optimale Fruchtfolgen im Ackerbau*. Agroscope. URL: https://ira.agroscope.ch/de-CH/publication/42952

Jetzke, T., Richter, S., Keppner, B., Domröse, L., Wunder, S. & Ferrari, A. (2022): *Focus on the future: Meat of the future. Trend report for assessing the environmental impacts of plant-based meat substitutes, edible insects and in vitro meat*. Umweltbundesamt. URL: https://www.umweltbundesamt.de/en/publikationen/focus-on-the-future-meat-of-the-future

Johne, C., Schröder, E. & Ward, H. (2023): The distributional effects of a nitrogen tax: Evidence from Germany. *Ecological Economics*, *208*. URL: https://doi.org/10.1016/j.ecolecon.2023.107815

Johnston, A. E., Poulton, P. R., Coleman, K., Macdonald, A. J. & White, R. P. (2017): Changes in soil organic matter over 70 years in continuous arable and ley–arable rotations on a sandy loam soil in England. *European Journal of Soil Science*, *68*(3), 305–316. URL: https://doi.org/10.1111/ejss.12415

Johnston, C. M. T. & Radeloff, V. C. (2019): Global mitigation potential of carbon stored in harvested wood products. *Proceedings of the National Academy of Sciences*, *116*(29), 14526–14531. URL: https://doi.org/10.1073/pnas.1904231116

Joosten, H. & Clarke, D. (2002): *Wise use of mires and peatlands: Background and principles including a framework for decision-making*. International Peat Society and International Mire Conservation Group. URL: https://www.researchgate.net/publication/293563126_Wise_use_of_mires_Background_and_principles

Jordon, M. W., Willis, K. J., Bürkner, P.-C. & Petrokofsky, G. (2022): Rotational grazing and multispecies herbal leys increase productivity in temperate pastoral systems. A meta-analysis. *Agriculture, Ecosystems & Environment*, *337*, 108075. URL: https://doi.org/10.1016/j.agee.2022.108075

Jose, S. (2009): Agroforestry for ecosystem services and environmental benefits: An overview. *Agroforestry Systems*, *76*(1), 1–10. URL: https://doi.org/10.1007/s10457-009-9229-7

JRC (Joint Research Centre) (2022): *Biomass flows: Data-Modelling platform of resource economics.* URL: https://datam.jrc.ec.europa.eu/datam/mashup/BIOMASS_FLOWS/index.html

JRC (Joint Research Centre) (2023): *Biomass production, supply, uses and flows in the European Union: Integrated assessment.* URL: https://data.europa.eu/doi/10.2760/484748

JRC (Joint Research Centre), Camia, A., Giuntoli, J., Jonsson, R., Robert, N., Cazzaniga, N. E., Jasinevičius, G., Avitabile, V., Grassi, G., Barredo, J. I. & Mubareka, S. (2021): *The Use of Woody Biomass for Energy Production in the EU*. URL: https://data.europa.eu/doi/10.2760/831621

Kalmar, R., Rauch, B., Dörr, J. & Liggesmeyer, P. (2022): Agricultural Data Space. In B. Otto, M. ten Hompel & S. Wrobel (Eds.), *Designing Data Spaces: The Ecosystem Approach to Competitive Advantage*, 279–290. URL: https://doi.org/10.1007/978-3-030-93975-5_17

Kämpf, I., Hölzel, N., Störrle, M., Broll, G. & Kiehl, K. (2016): Potential of temperate agricultural soils for carbon sequestration: A meta-analysis of land-use effects. *Science of The Total Environment*, *566–567*, 428–435. URL: https://doi.org/10.1016/j.scitotenv.2016.05.067

Kanzler, M., Böhm, C., Mirck, J., Schmitt, D. & Veste, M. (2019): Microclimate effects on evaporation and winter wheat (Triticum aestivum L.) yield within a temperate agroforestry system. *Agroforestry Systems*, *93*(5), 1821–1841. URL: https://doi.org/10.1007/s10457-018-0289-4

Kebreab, E., Bannink, A., Pressman, E. M., Walker, N., Karagiannis, A., van Gastelen, S. & Dijkstra, J. (2023): A meta-analysis of effects of 3-nitrooxypropanol on methane production, yield, and intensity in dairy cattle. *Journal of Dairy Science*, *106*(2), 927–936. URL: https://doi.org/10.3168/jds.2022-22211

Kim, D., Kock, M. A., Lamping, M., Batista, P. H. D., Hilty, R., Slowinski, P. R. & Steinhart, M. (2023): *New Genomic Techniques and Intellectual Property Law: Challenges and Solutions for the Plant Breeding Sector*. Max Planck Institute for Innovation and Competition Research, Paper No. 23-16. URL: https://papers.ssrn.com/abstract=4537299

Klaus, F., Tscharntke, T. & Grass, I. (2023): Trophic level and specialization moderate effects of habitat loss and landscape diversity on cavity-nesting bees, wasps and their parasitoids. *Insect Conservation and Diversity*. URL: https://doi.org/10.1111/icad.12688

Kleijn, D., Berendse, F., Smit, R., Gilissen, N., Smit, J., Brak, B. & Groeneveld, R. (2004): Ecological effectiveness of agri-environment schemes in different agricultural landscapes in the Netherlands. *Conservation Biology*, *18*(3), 775–786. URL: https://doi.org/10.1111/j.1523-1739.2004.00550.x

Kløve, B., Berglund, K., Berglund, Ö., Weldon, S. & Maljanen, M. (2017): Future options for cultivated Nordic peat soils: Can land management and rewetting control greenhouse gas emissions? *Environmental Science & Policy*, *69*, 85–93. URL: https://doi.org/10.1016/j.envsci.2016.12.017

KNE (Kompetenzzentrum Naturschutz Energiewende) (2022): *Photovoltaik auf wiedervernässten Moorböden: Eine neue Flächenkulisse im EEG 2023*. URL: https://www.naturschutz-energiewende.de/wp-content/uploads/KNE_Photovoltaik_auf-wiedervernaessten_Moorboeden.pdf

Komal, J., Desai, H. R., Samal, I., Mastinu, A., Patel, R. D., Kumar, P. V. D., Majhi, P. K., Mahanta, D. K. & Bhoi, T. K. (2023): Unveiling the genetic symphony: Harnessing CRISPR-Cas genome editing for effective insect pest management. *Plants*, *12*(23), 3961. URL: https://doi.org/10.3390/plants12233961

Kompetenznetzwerk Nutztierhaltung. (2020): *Empfehlungen des Kompetenznetzwerks Nutztierhaltung. 11. Februar 2020*. URL: https://www.bmel.de/SharedDocs/Downloads/DE/_Tiere/Nutztiere/200211-empfehlung-kompetenznetzwerk-nutztierhaltung.pdf?__blob=publicationFile&v=3

Korosuo, A., Pilli, R., Abad Viñas, R., Blujdea, V. N. B., Colditz, R. R., Fiorese, G., Rossi, S., Vizzarri, M. & Grassi, G. (2023): The role of forests in the EU climate policy: Are we on the right track? *Carbon Balance and Management*, *18*(1), 15. URL: https://doi.org/10.1186/s13021-023-00234-0

Kosior, K. (2021): Towards a Common Agricultural Data Space in the European Union: A sustainable development perspective. *Wieś i Rolnictwo*, *2 (191)*, 65–89. URL: https://doi.org/10.53098/wir022021/03

Kotowski, W., Acreman, M., Grootjans, A., Klimkowska, A., Rößling, H. & Wheeler, B. (2016): Restoration of temperate fens: Matching strategies with site potential. In: A. Bonn., T. Allott, M. Evans, H. Joosten & R. Stoneman (Eds.), *Peatland Restoration and Ecosystem Services*. 1st ed., 170–191. URL: https://doi.org/10.1017/CBO9781139177788.011

Kougias, P. G. & Angelidaki, I. (2018): Biogas and its opportunities: A review. *Frontiers of Environmental Science & Engineering*, *12*(3), 14. URL: https://doi.org/10.1007/s11783-018-1037-8

Kowalski, A. S., Loustau, D., Berbigier, P., Manca, G., Tedeschi, V., Borghetti, M., Valentini, R., Kolari, P., Berninger, F., Rannik, U., Hari, P., Rayment, M., Mencuccini, M., Moncrieff, J. & Grace, J. (2004): Paired comparisons of carbon exchange between undisturbed and regenerating stands in four managed forests in Europe. *Global Change Biology*, *10*(10), 1707–1723. URL: https://doi.org/10.1111/j.1365-2486.2004.00846.x

Kozicka, M., Havlík, P., Valin, H., Wollenberg, E., Deppermann, A., Leclère, D., Lauri, P., Moses, R., Boere, E., Frank, S., Davis, C., Park, E. & Gurwick, N. (2023): Feeding climate and biodiversity goals with novel plant-based meat and milk alternatives. *Nature Communications*, *14*, 5316. URL: https://doi.org/10.1038/s41467-023-40899-2

Kremen, C. & Merenlender, A. M. (2018): Landscapes that work for biodiversity and people. *Science*, *362*(6412). URL: https://doi.org/10.1126/science.aau6020

Kreyling, J., Tanneberger, F., Jansen, F., Van Der Linden, S., Aggenbach, C., Blüml, V., Couwenberg, J., Emsens, W.-J., Joosten, H., Klimkowska, A., Kotowski, W., Kozub, L., Lennartz, B., Liczner, Y., Liu, H., Michaelis, D., Oehmke, C., Parakenings, K., Pleyl, E., ... Jurasinski, G. (2021): Rewetting does not return drained fen peatlands to their old selves. *Nature Communications*, *12*(1), 5693. URL: https://doi.org/10.1038/s41467-021-25619-y

KTBL (Kuratorium für Technik und Bauwesen in der Landwirtschaft e. V.) (2023): *Verwendung erneuerbarer Antriebsenergien in landwirtschaftlichen Maschinen*. URL: https://www.ktbl.de/fileadmin/user_upload/Artikel/Energie/Antriebsenergien/12643_Antriebssysteme.pdf

Kudsk, P., Jørgensen, L. N. & Ørum, J. E. (2018): Pesticide load: A new Danish pesticide risk indicator with multiple applications. *Land Use Policy*, *70*, 384–393. URL: https://doi.org/10.1016/j.landusepol.2017.11.010

Lacetera, N. (2019): Impact of climate change on animal health and welfare. *Animal Frontiers*, *9*(1), 26–31. URL: https://doi.org/10.1093/af/vfy030

Laderchi, C. R., Lotze-Campen, H., DeClerck, F., Bodirsky, B., Collignon, Q., Crawford, M., Dietz, S. & Fesenfeld, L. (2024): *The Economics of the Food System Transformation*. Food System Economics Commission. URL: https://foodsystemeconomics.org/wp-content/uploads/FSEC-Global_Policy_Report.pdf

Lahtinen, L., Mattila, T., Myllyviita, T., Seppälä, J. & Vasander, H. (2022): Effects of paludiculture products on reducing greenhouse gas emissions from agricultural peatlands. *Ecological Engineering*, *175*. URL: https://doi.org/10.1016/j.ecoleng.2021.106502

Laidig, F., Feike, T., Lichthardt, C., Schierholt, A. & Piepho, H. P. (2024): Breeding progress of nitrogen use efficiency of cereal crops, winter oilseed rape and peas in long-term variety trials. *Theoretical and Applied Genetics*, *137*(2), 45. URL: https://doi.org/10.1007/s00122-023-04521-9

Lakner, S. & Röder, N. (2024): *Bauernproteste: EU-Kommission schreddert Umweltstandards in der Landwirtschaft*. Lakners Kommentare. URL: https://slakner.wordpress.com/2024/04/02/bauernproteste-eu-kommission-schreddert-umweltstandards-in-der-landwirtschaft/

Lammerts van Bueren, E. T. & Struik, P. C. (2017): Diverse concepts of breeding for nitrogen use efficiency: A review. *Agronomy for Sustainable Development*, *37*(5), 50. URL: https://doi.org/10.1007/s13593-017-0457-3

Lange, S., Santarius, T. & Dencik, L. (2023): *Digital Reset: Redirecting Technologies for the Deep Sustainability Transformation*. URL: https://www.oekom.de/buch/digital-reset-9783987260223

Langridge, P., Braun, H., Hulke, B., Ober, E. & Prasanna, B. M. (2021): Breeding crops for climate resilience. *Theoretical and Applied Genetics*, *134*(6), 1607–1611. URL: https://doi.org/10.1007/s00122-021-03854-7

Lechenet, M., Dessaint, F., Py, G., Makowski, D. & Munier-Jolain, N. (2017): Reducing pesticide use while preserving crop productivity and profitability on arable farms. *Nature Plants*, *3*(3), 1–6. URL: https://doi.org/10.1038/nplants.2017.8

Lefebvre, M., Langrell, S. R. H. & Gomez-y-Paloma, S. (2015): Incentives and policies for integrated pest management in Europe: A review. *Agronomy for Sustainable Development*, *35*(1), 27–45. URL: https://doi.org/10.1007/s13593-014-0237-2

Lehtonen, H., Huan-Niemi, E. & Niemi, J. (2022): The transition of agriculture to low carbon pathways with regional distributive impacts. *Environmental Innovation and Societal Transitions*, *44*, 1–13. URL: https://doi.org/10.1016/j.eist.2022.05.002

Lehtoranta, S., Tampio, E., Rasi, S., Laakso, J., Vikki, K. & Luostarinen, S. (2024): The implications of management practices on life cycle greenhouse gas emissions in biogas production. *Journal of Environmental Management*, *366*, 121884. URL: https://doi.org/10.1016/j.jenvman.2024.121884

Leip, A., Billen, G., Garnier, J., Grizzetti, B., Lassaletta, L., Reis, S., Simpson, D., Sutton, M. A., de Vries, W., Weiss, F. & Westhoek, H. (2015): Impacts of European livestock production: Nitrogen, sulphur, phosphorus and greenhouse gas emissions, land-use, water eutrophication and biodiversity. *Environmental Research Letters*, *10*(11), 115004. URL: https://doi.org/10.1088/1748-9326/10/11/115004

Leip, A., Britz, W., Weiss, F. & de Vries, W. (2011): Farm, land, and soil nitrogen budgets for agriculture in Europe calculated with CAPRI. *Environmental Pollution*, *159*(11), 3243–3253. URL: https://doi.org/10.1016/j.envpol.2011.01.040

Leopoldina, acatech & The Union of the German Academies of Sciences and Humanities (2020): *Biodiversity and Management of Agricultural Landscapes: Wide-ranging Action is now crucial*. Leopoldina, German National Academy of Sciences; acatech, National Academy of Science and Engineering; The Union of German Academies of Sciences and Humanities. URL: https://www.leopoldina.org/en/publications/detailview/publication/biodiversity-and-management-of-agricultural-landscapes-2020/

Leteinturier, B., Herman, J. L., Longueville, F. de, Quintin, L. & Oger, R. (2006): Adaptation of a crop sequence indicator based on a land parcel management system. *Agriculture, Ecosystems & Environment*, *112*(4), 324–334. URL: https://doi.org/10.1016/j.agee.2005.07.011

Leturcq, P. (2020): GHG displacement factors of harvested wood products: The myth of substitution. *Scientific Reports*, *10*(1). URL: https://doi.org/10.1038/s41598-020-77527-8

Li, X.-F., Wang, Z.-G., Bao, X.-G., Sun, J.-H., Yang, S.-C., Wang, P., Wang, C.-B., Wu, J.-P., Liu, X.-R., Tian, X.-L., Wang, Y., Li, J.-P., Wang, Y., Xia, H.-Y., Mei, P.-P., Wang, X.-F., Zhao, J.-H., Yu, R.-P., Zhang, W.-P., … Li, L. (2021): Long-term increased grain yield and soil fertility from intercropping. *Nature Sustainability*, *4*(11), 943–950. URL: https://doi.org/10.1038/s41893-021-00767-7

Lichtenberg, E. M., Kennedy, C. M., Kremen, C., Batáry, P., Berendse, F., Bommarco, R., Bosque-Pérez, N. A., Carvalheiro, L. G., Snyder, W. E., Williams, N. M., Winfree, R., Klatt, B. K., Åström, S., Benjamin, F., Brittain, C., Chaplin-Kramer, R., Clough, Y., Danforth, B., Diekötter, T., … Crowder, D. W. (2017): A global synthesis of the effects of diversified farming systems on arthropod diversity within fields and across agricultural landscapes. *Global Change Biology*, *23*(11), 4946–4957. URL: https://doi.org/10.1111/gcb.13714

Lillemets, J., Fertő, I. & Viira, A.-H. (2022): The socio-economic impacts of the CAP: Systematic literature review. *Land Use Policy*, *114*, 105968. URL: https://doi.org/10.1016/j.landusepol.2021.105968

Lindow, K., Strid, I., Olsson, M., Wallgren, T., Lundh, Å., Östman, Ö., Persson Hovmalm, H., Larsson Jönsson, H., Stenberg, J. A. & Östergren, K. (2021): Food loss in Sweden: National follow-up methods for increased knowledge about losses and resources in food production. *Rapport / Jordbruksverket*, *2021, 2*. URL: https://res.slu.se/id/publ/113844

Lioutas, E. D., Charatsari, C. & De Rosa, M. (2021): Digitalization of agriculture: A way to solve the food problem or a trolley dilemma? *Technology in Society*, *67*. URL: https://doi.org/10.1016/j.techsoc.2021.101744

Lipper, L., McCarthy, N., Zilberman, D., Asfaw, S. & Branca, G. (Eds.) (2018): *Climate Smart Agriculture: Building Resilience to Climate Change*. URL: https://doi.org/10.1007/978-3-319-61194-5

Lóránt, A. & Allen, B. (2019): *Net-zero agriculture in 2050: How to get there?* IEEP, Institute for European Environmental Policy. URL: https://ieep.eu/wp-content/uploads/2022/12/IEEP_NZ2050_Agriculture_report_screen.pdf

Lorenz, K. & Lal, R. (2016): *Soil organic carbon: An appropriate indicator to monitor trends of land and soil degradation within the SDG Framework?* Umweltbundesamt. URL: https://www.umweltbundesamt.de/en/publikationen/soil-organic-carbon-an-appropriate-indicator-to

Loza, C., Reinsch, T., Loges, R., Taube, F., Gere, J. I., Kluß, C., Hasler, M. & Malisch, C. S. (2021): Methane emission and milk production from jersey sows grazing perennial ryegrass–white clover and multispecies forage mixtures. *Agriculture*, *11*(2), 175. URL: https://doi.org/10.3390/agriculture11020175

Lüker-Jans, N., Simmering, D. & Otte, A. (2017): The impact of biogas plants on regional dynamics of permanent grassland and maize area: The example of Hesse, Germany (2005–2010). *Agriculture, Ecosystems & Environment*, *241*, 24–38. URL: https://doi.org/10.1016/j.agee.2017.02.023

Luo, J., Ledgard, S., Wise, B., Welten, B., Lindsey, S., Judge, A. & Sprosen, M. (2015): Effect of dicyandiamide (DCD) delivery method, application rate, and season on pasture urine patch nitrous oxide emissions. *Biology and Fertility of Soils*, *51*(4), 453–464. URL: https://doi.org/10.1007/s00374-015-0993-4

Luo, L., Cohan, D. S., Gurung, R. B., Venterea, R. T., Ran, L., Benson, V. & Yuan, Y. (2024): Impacts assessment of nitrification inhibitors on U.S. agricultural emissions of reactive nitrogen gases. *Journal of Environmental Management*, *359*, 121043. URL: https://doi.org/10.1016/j.jenvman.2024.121043

Luyckx, K., Bowman, M., Taillard, D. & Broeze, J. (2019): *The Safety, Environmental and Economic Aspects of Feeding Treated Surplus Food to Omnivorous Livestock*. Deliverable 6.7 of the EU research project REFRESH. URL: https://eu-refresh.org/technical-guidelines-animal-feed.html

Lyngs, T. B. (2024): Social conditionality: An adequate legal response to challenges faced by agricultural workers in the EU, or an example of redwashing within the Common Agricultural Policy? *European Labour Law Journal*. URL: https://doi.org/10.1177/20319525241242794

Ma, S., Churkina, G., Gessler, A., Wieland, R. & Bellocchi, G. (2016): Yield gap of winter wheat in Europe and sensitivity of potential yield to climate factors. *Climate Research*, *67*(3), 179–190. URL: https://doi.org/10.3354/cr01367

Maes, J., Teller, A., Erhard, M., Conde, S., Vallecillo, R. S., Barredo, C. J. I., Paracchini, M.-L., Abdul, M. D., Trombetti, M., Vigiak, O., Zulian, G., Addamo, A., Grizzetti, B., Somma, F., Hagyo, A., Vogt, P., Polce, C., Jones, A., Marin, A., … Santos-Martín, F. (2020): *Mapping and Assessment of Ecosystems and their Services: An EU Ecosystem Assessment*. URL: https://doi.org/10.2760/757183

Magnolo, F., Dekker, H., Decorte, M., Bezzi, G., Rossi, L., Meers, E. & Speelman, S. (2021): The role of sequential cropping and Biogasdoneright™ in enhancing the sustainability of agricultural systems in Europe. *Agronomy*, *11*(11), 2102. URL: https://doi.org/10.3390/agronomy11112102

Mahmud, K., Panday, D., Mergoum, A. & Missaoui, A. (2021): Nitrogen losses and potential mitigation strategies for a sustainable agroecosystem. *Sustainability*, *13*(4), 2400. URL: https://doi.org/10.3390/su13042400

Man, K. Y., Chow, K. L., Man, Y. B., Mo, W. Y. & Wong, M. H. (2021): Use of biochar as feed supplements for animal farming. *Critical Reviews in Environmental Science and Technology*, *51*(2), 187–217. URL: https://doi.org/10.1080/10643389.2020.1721980

Marini, L., Batáry, P. & Tscharntke, T. (2023): Testing the potential benefits of small fields for biocontrol needs a landscape perspective. *Proceedings of the National Academy of Sciences of the United States of America*, *120*(1). URL: https://doi.org/10.1073/pnas.2218447120

Markets and Markets (2021): *Meat Substitutes, Market Size, Share and Growth Report - Forecast 2027*. URL: https://www.marketsandmarkets.com/Market-Reports/meat-substitutes-market-979.html

Martens, H. R., Laage, K., Eickmanns, M., Drexler, A., Heinsohn, V., Wegner, N., Muster, C., Diekmann, M., Seeber, E., Kreyling, J., Michalik, P. & Tanneberger, F. (2023): Paludiculture can support biodiversity conservation in rewetted fen peatlands. *Scientific Reports*, *13*(1). URL: https://doi.org/10.1038/s41598-023-44481-0

Martin, E. A., Dainese, M., Clough, Y., Báldi, A., Bommarco, R., Gagic, V., Garratt, M. P. D., Holzschuh, A., Kleijn, D., Kovács-Hostyánszki, A., Marini, L., Potts, S. G., Smith, H. G., Al Hassan, D., Albrecht, M., Andersson, G. K. S., Asís, J. D., Aviron, S., Balzan, M. V., … Steffan-Dewenter, I. (2019): The interplay of landscape composition and configuration: New pathways to manage functional biodiversity and agroecosystem services across Europe. *Ecology Letters*, *22*(7), 1083–1094. URL: https://doi.org/10.1111/ele.13265

Martin, N. & Couwenberg, J. (2021): *Organic soils in National Inventory Submissions of EU Countries*. Proceedings of the Greifswald Mire Centre 05/2021. URL: https://www.greifswaldmoor.de/files/dokumente/GMC%20Schriften/2021_Martin&Couwenberg.pdf

Material Economics (2019): *Industrial Transformation 2050: Pathways to Net-Zero Emissions from EU Heavy Industry*. URL: https://materialeconomics.com/node/13

Material Economics (2021): *EU Biomass Use in a Net-Zero Economy – A Course Correction for EU Biomass and Bioresources within a Net-Zero Emissions Economy: Making a Sustainable Approach Possible. Assumptions and methodology underlying the sectoral analysis.* Technical Annex, Version 1.0. URL: https://materialeconomics.com/sites/default/files/2024-06/2021-019-etc-bio-economy-technical-annex-web-aw.pdf

Mathias, E. & Robert, C. (2020): *La biomasse énergie est-elle neutre en carbone?* Citepa. URL: https://www.citepa.org/wp-content/uploads/3.2-Biomasse-%C3%A9nergie-et-neutralit%C3%A9-carbone.pdf

Mathias, Y. (2022): *Financing Mechanisms in Europe for Restoring Peatlands: An Overview of the Different Financing Opportunities Existing for Peatland Restoration*. Interreg North-West Europe. URL: https://vb.nweurope.eu/media/19450/financing-mechanisms-for-rewetting-peatlands_vf.pdf

Matthews, A. (2018): *National Co-Financing of CAP Direct Payments*. URL: https://www.sieps.se/en/publications/2018/national-co-financing-of-cap-direct-payments/

McDonald et al. (2023): *QU.A.L.ITY Soil Carbon Removals?* URL: https://www.oeko.de/publikation/quality-soil-carbon-removals/

McGee, M., Regan, M., Moloney, A. P., O'Riordan, E. G., Lenehan, C., Kelly, A. K. & Crosson, P. (2024): Grass-based finishing of early- and late-maturing breed bulls within suckler beef systems: Performance, profitability, greenhouse gas emissions and feed-food competition. *Livestock Science*, *279*, 105392. URL: https://doi.org/10.1016/j.livsci.2023.105392

McGuire, R., Williams, P. N., Smith, P., McGrath, S. P., Curry, D., Donnison, I., Emmet, B. & Scollan, N. (2022): Potential co-benefits and trade-offs between improved soil management, climate change mitigation and agri-food productivity. *Food and Energy Security*, *11*(2). URL: https://doi.org/10.1002/fes3.352

Medawar, E., Huhn, S., Villringer, A. & Veronica Witte, A. (2019): The effects of plant-based diets on the body and the brain: A systematic review. *Translational Psychiatry*, *9*(1), 1–17. URL: https://doi.org/10.1038/s41398-019-0552-0

Medda, S., Fadda, A. & Mulas, M. (2022): Influence of climate change on metabolism and biological characteristics in perennial woody fruit crops in the Mediterranean environment. *Horticulturae*, *8*(4), 273. URL: https://doi.org/10.3390/horticulturae8040273

Merfort, L., Bauer, N., Humpenöder, F., Klein, D., Strefler, J., Popp, A., Luderer, G. & Kriegler, E. (2023): Bioenergy-induced land-use-change emissions with sectorally fragmented policies. *Nature Climate Change*, *13*(7), 685–692. URL: https://doi.org/10.1038/s41558-023-01697-2

Mesnage, R., Straw, E. A., Antoniou, M. N., Benbrook, C., Brown, M. J. F., Chauzat, M.-P., Finger, R., Goulson, D., Leadbeater, E., López-Ballesteros, A., Möhring, N., Neumann, P., Stanley, D., Stout, J. C., Thompson, L. J., Topping, C. J., White, B., Zaller, J. G. & Zioga, E. (2021): Improving pesticide-use data for the EU. *Nature Ecology & Evolution*, *5*(12), 1560–1560. URL: https://doi.org/10.1038/s41559-021-01574-1

Meyer-Ohlendorf, N. (2023): *Making Carbon Removals a Real Climate Solution*. Ecologic Institute. URL: https://www.ecologic.eu/19290

Meyer-Ohlendorf, N., Kocher, D., Gores, S. & Graichen, J. (2023): *EU 2040 Climate Target and Framework: The Role of Carbon Removals*. Ecologic Institute. URL: https://www.ecologic.eu/19509

Midler, E., Scheid, A., Pagnon, J. & Nadeu, E. (2023): *Environmental and Climate Assessments of CAP Strategic Plans*. IEEP, Institute for European Environmental Policy. URL: https://www.ecologic.eu/19224

Miezïte, L. E., Ameztegui, A., De Cáceres, M., Coll, L., Morán-Ordóñez, A., Vega-García, C. & Rodrigues, M. (2023): Trajectories of wildfire behavior under climate change. Can forest management mitigate the increasing hazard? *Journal of Environmental Management*, *322*, 116134. URL: https://doi.org/10.1016/j.jenvman.2022.116134

Milazzo, F., Abdalla, M., Ravetto Enri, S., Pittarello, M., Hejduk, S., Newell-Price, P., Schils, R., Smith, P. & Vanwalleghem, T. (2023): An overview of permanent grassland grazing management practices and the impacts on principal soil quality indicators. *Agronomy*, *13*(5), 1366. URL: https://doi.org/10.3390/agronomy13051366

Millinger, M., Meisel, K., Budzinski, M. & Thrän, D. (2018): Relative greenhouse gas abatement cost competitiveness of biofuels in Germany. *Energies*, *11*(3). URL: https://doi.org/10.3390/en11030615

Minet, E. P., Jahangir, M. M. R., Krol, D. J., Rochford, N., Fenton, O., Rooney, D., Lanigan, G., Forrestal, P. J., Breslin, C. & Richards, K. G. (2016): Amendment of cattle slurry with the nitrification inhibitor dicyandiamide during storage: A new effective and practical N_2O mitigation measure for landspreading. *Agriculture, Ecosystems & Environment*, *215*, 68–75. URL: https://doi.org/10.1016/j.agee.2015.09.014

Ministry of Food, Agriculture and Fisheries of Denmark (2021): *The Official Dietary Guidelines: Good for Health and Climate*. Ministry of Food, Agriculture and Fisheries. The Danish Veterinary and Food Administration. URL: https://foedevarestyrelsen.dk/Media/638194807769097944/Danish_Official_Dietary_Guidelines_Good_for_Health_and_climate_2021_PRINT_ENG__webtil.pdf

Mohamed, A., DeClerck, F., Verburg, P. H., Obura, D., Abrams, J. F., Zafra-Calvo, N., Rocha, J., Estrada-Carmona, N., Fremier, A., Jones, S. K., Meier, I. C. & Stewart-Koster, B. (2024): Securing nature's contributions to people requires at least 20%–25% (semi-)natural habitat in human-modified landscapes. *One Earth*, *7*(1), 59–71. URL: https://doi.org/10.1016/j.oneear.2023.12.008

Möhring, N., Ingold, K., Kudsk, P., Martin-Laurent, F., Niggli, U., Siegrist, M., Studer, B., Walter, A. & Finger, R. (2020): Pathways for advancing pesticide policies. *Nature Food*, *1*(9), 535–540. URL: https://doi.org/10.1038/s43016-020-00141-4

Möhring, N., Kanter, D., Aziz, T., Castro, I. B., Maggi, F., Schulte-Uebbing, L., Seufert, V., Tang, F. H. M., Zhang, X. & Leadley, P. (2023): Successful implementation of global targets to reduce nutrient and pesticide pollution requires suitable indicators. *Nature Ecology & Evolution*. URL: https://doi.org/10.1038/s41559-023-02120-x

Montes, F., Meinen, R., Dell, C., Rotz, A., Hristov, A. N., Oh, J., Waghorn, G., Gerber, P. J., Henderson, B., Makkar, H. P. S. & Dijkstra, J. (2013): SPECIAL TOPICS: Mitigation of methane and nitrous oxide emissions from animal operations: II. A review of manure management mitigation options. *Journal of Animal Science*, *91*(11), 5070–5094. URL: https://doi.org/10.2527/jas.2013-6584

Mosquera-Losada, M. R., Santos, M. G. S., Gonçalves, B., Ferreiro-Domínguez, N., Castro, M., Rigueiro-Rodríguez, A., González-Hernández, M. P., Fernández-Lorenzo, J. L., Romero-Franco, R., Aldrey-Vázquez, J. A., Sobrino, C. C., García-Berrios, J. J. & Santiago-Freijanes, J. J. (2023): Policy challenges for agroforestry implementation in Europe. *Frontiers in Forests and Global Change*, *6*. URL: https://doi.org/10.3389/ffgc.2023.1127601

Mouratiadou, I., Lemke, N., Chen, C., Wartenberg, A., Bloch, R., Donat, M., Gaiser, T., Basavegowda, D. H., Helming, K., Hosseini Yekani, S. A., Krull, M., Lingemann, K., Macpherson, J., Melzer, M., Nendel, C., Piorr, A., Shaaban, M., Zander, P., Weltzien, C. & Bellingrath-Kimura, S. D. (2023): The Digital Agricultural Knowledge and Information System (DAKIS): Employing digitalisation to encourage diversified and multifunctional agricultural systems. *Environmental Science and Ecotechnology*, *16*. URL: https://doi.org/10.1016/j.ese.2023.100274

Münch, A., Badouix, M. & Gorny, H. (2023): *Research for AGRI Committee: Comparative analysis of the CAP Strategic Plans and their effective contribution to the achievement of the EU objectives*. European Parliament, Policy Department for Structural and Cohesion Policies. URL: https://www.europarl.europa.eu/thinktank/en/document/IPOL_STU(2023)747255

Munzel, B., Jetton, V. & Dr. Schmitz, N. (2024): *Möglichkeiten des Carbon Crediting für Waldbesitzende*. ClimatePal Service GmbH. URL: https://www.wald-ist-klimaschuetzer.de/2024/04/08/climatepal-studie-zu-co2-gutschriften/

Muscat, A., de Olde, E. M., de Boer, I. J. M. & Ripoll-Bosch, R. (2020): The battle for biomass: A systematic review of food-feed-fuel competition. *Global Food Security*, *25*. URL: https://doi.org/10.1016/j.gfs.2019.100330

Nabuurs, G.-J., Delacote, P., Ellison, D., Hanewinkel, M., Hetemäki, L. & Lindner, M. (2017): By 2050 the mitigation effects of EU forests could nearly double through climate smart forestry. *Forests*, *8*(12), 14. URL: https://doi.org/10.3390/f8120484

Naegeli de Torres, F., Brödner, R., Cyffka, K.-F., Fais, A., Kalcher, J., Kazmin, S., Meyer, R., Radtke, K. S., Richter, F., Selig, M., Wilske, B. & Thrän, D. (2023): *DBFZ Resource Database: DE-Biomass Monitor. Biomass Potentials and Utilization of Biogenic Wastes and Residues in Germany 2010–2020*. URL: https://doi.org/10.5281/zenodo.10370137

Nakaishi, T. & Takayabu, H. (2022): Production efficiency of animal feed obtained from food waste in Japan. *Environmental Science and Pollution Research*, *29*(40), 61187–61203. URL: https://doi.org/10.1007/s11356-022-20221-1

Närmann, F., Birr, F., Kaiser, M., Nerger, M., Luthardt, V., Zeitz, J. & Tanneberger, F. (2021): *Klimaschonende, biodiversitätsfördernde Bewirtschaftung von Niedermoorböden*. Bundesamt für Naturschutz. URL: https://doi.org/10.19217/skr616

Nath, P. C., Ojha, A., Debnath, S., Sharma, M., Nayak, P. K., Sridhar, K. & Inbaraj, B. S. (2023): Valorization of food waste as animal feed: A step towards sustainable food waste management and circular bioeconomy. *Animals*, *13*(8), 1366. URL: https://doi.org/10.3390/ani13081366

NEGEM Project (2023): *Quantifying and Deploying Responsible Negative Emissions. Science-policy brief.* URL: https://www.negemproject.eu/results/

Neidermeier, A. N., Zagaria, C., Pampanoni, V., West, T. A. P. & Verburg, P. H. (2023): Mapping opportunities for the use of land management strategies to address fire risk in Europe. *Journal of Environmental Management*, *346*, 118941. URL: https://doi.org/10.1016/j.jenvman.2023.118941

Neuenfeldt, S., Gocht, A., Heckelei, T. & Ciaian, P. (2019): Explaining farm structural change in the European agriculture: A novel analytical framework. *European Review of Agricultural Economics*, *46*(5), 713–768. URL: https://doi.org/10.1093/erae/jby037

Nguyen, C., Latacz-Lohmann, U., Hanley, N., Schilizzi, S. & Iftekhar, S. (2022): Spatial coordination incentives for landscape-scale environmental management: A systematic review. *Land Use Policy*, *114*. URL: https://doi.org/10.1016/j.landusepol.2021.105936

Ngwabie, N. M., Gordon, R. J., VanderZaag, A., Dunfield, K., Sissoko, A. & Wagner-Riddle, C. (2016): The extent of manure removal from storages and its impact gaseous emissions. *Journal of Environmental Quality*, *45*(6), 2023–2029. URL: https://doi.org/10.2134/jeq2016.01.0004

Nordt, A., Abel, S., Hirschelmann, S., Lechtape, C. & Neubert, J. (2022): *Leitfaden für die Umsetzung von Paludikultur.* Greifswald Moor Centrum-Schriftenreihe 05/2022. URL: https://www.greifswaldmoor.de/files/dokumente/GMC%20Schriften/2022-05_Nordt%20et%20al_Paludikultur%20Leitfaden.pdf

Nordt, A. & Dahms, T. (2021): *Paludi-tiny house: A demonstrator for climate friendly building materials.* Poster Presentation. URL: https://www.moorwissen.de/files/doc/veranstaltungen/rrr2021/downloads/beitraege/RRR2021_3.1.C_Nordt_Poster.pdf

Nowack, W., Popp, T. R., Schmid, J. C. & Grethe, H. (2023): Does agricultural structural change lead to a weakening of the sector's social functions? A case study from North-west Germany. *Journal of Rural Studies*, *100*, 103034. URL: https://doi.org/10.1016/j.jrurstud.2023.103034

Nowack, W., Schmid, J. C. & Grethe, H. (2021): Social dimensions of multifunctional agriculture in Europe—Towards an interdisciplinary framework. *International Journal of Agricultural Sustainability*, *20*(5), 758–773. URL: https://doi.org/10.1080/14735903.2021.1977520

OECD (Organisation for Economic Co-operation and Development) (2013): *Providing Agri-environmental Public Goods through Collective Action*. URL: https://www.oecd.org/environment/providing-agri-environmental-public-goods-through-collective-action-9789264197213-en.htm

OECD (Organisation for Economic Co-operation and Development) (2019): *The Heavy Burden of Obesity: The Economics of Prevention*. URL: https://www.oecd.org/health/the-heavy-burden-of-obesity-67450d67-en.htm

OECD (Organisation for Economic Co-operation and Development) (2020): *Towards Sustainable Land Use: Aligning Biodiversity, Climate and Food Policies*. URL: https://www.oecd.org/environment/towards-sustainable-land-use-3809b6a1-en.htm

OECD (Organisation for Economic Co-operation and Development) (2021): *Making Better Policies for Food systems*. URL: https://www.oecd-ilibrary.org/agriculture-and-food/making-better-policies-for-food-systems_ddfba4de-en

OECD (Organisation for Economic Co-operation and Development) & European Union (2022): *Health at a Glance: Europe 2022: State of Health in the EU Cycle*. URL: https://health.ec.europa.eu/state-health-eu/health-glance-europe_en

Oenema, O., Witzke, H. P., Klimont, Z., Lesschen, J. P. & Velthof, G. L. (2009): Integrated assessment of promising measures to decrease nitrogen losses from agriculture in EU-27. *Agriculture, Ecosystems & Environment*, *133*(3), 280–288. URL: https://doi.org/10.1016/j.agee.2009.04.025

Offer, A. (2020): Bedeutung der Kulturkosten bei forstlichen Bewertungen. *AFZ Der Wald, 10/2020*. URL: https://www.fsv-offer.de/wp-content/uploads/2020/08/15-bedeutung-kulturkosten-wertermittlung.pdf

Offermann, R., Seidenberger, T., Thrän, D., Kaltschmitt, M., Zinoviev, S. & Miertus, S. (2011): Assessment of global bioenergy potentials. *Mitigation and Adaptation Strategies for Global Change*, *16*(1), 103–115. URL: https://doi.org/10.1007/s11027-010-9247-9

Oppermann, R., Pfister, S. C. & Eirich, A. (Eds.) (2020): *Sicherung der Biodiversität in der Agrarlandschaft: Quantifizierung des Maßnahmenbedarfs und Empfehlungen zur Umsetzung*. IFAB, Institut für Agrarökologie und Biodiversität.

Osei-Assibey, G., Dick, S., Macdiarmid, J., Semple, S., Reilly, J. J., Ellaway, A., Cowie, H. & McNeill, G. (2012): *The influence of the food environment on overweight and obesity in young children: A systematic review. BMJ Open, 2(6), e001538.* URL: https://doi.org/10.1136/bmjopen-2012-001538

Pachauri, R. K., Mayer, L. & IPCC (Intergovernmental Panel on Climate Change) (Eds.) (2015): *Climate Change 2014: Synthesis Report*. URL: https://www.ipcc.ch/report/ar5/syr/

Panagos, P., Ballabio, C., Himics, M., Scarpa, S., Matthews, F., Bogonos, M., Poesen, J. & Borrelli, P. (2021): Projections of soil loss by water erosion in Europe by 2050. *Environmental Science & Policy*, *124*, 380–392. URL: https://doi.org/10.1016/j.envsci.2021.07.012

Paracchini, M. L., Condé, S., d'Andrimont, R., Eiselt, B., Fernandez Uglade, O., Gervasini, E., Jones, A., Kovacevici, V., Oppermann, R. & Orgiazzi. (2020): The challenge of monitoring biodiversity in agricultural landscapes at the EU level. In: *Reconciling agricultural production with biodiversity conservation*. Burleigh Dodds Series in Agricultural Science. URL: https://doi.org/10.19103/AS.2020.0071.04

Parajuli, R., Thoma, G. & Matlock, M. D. (2019): Environmental sustainability of fruit and vegetable production supply chains in the face of climate change: A review. *Science of The Total Environment*, *650*, 2863–2879. URL: https://doi.org/10.1016/j.scitotenv.2018.10.019

Parsons, K. (2019): Brief 3: Integrated food policy: What is it and how can it help connect food systems. In: Centre for Food Policy: *Rethinking Food Policy: A Fresh Approach to Policy and Practice*. URL: https://www.city.ac.uk/__data/assets/pdf_file/0003/570441/7643_Brief-3_Integrated_food_policy_What_is_it_and_how_can_it_help_connect_food_systems_WEB_SP.pdf

Patacca, M., Lindner, M., Lucas-Borja, M. E., Cordonnier, T., Fidej, G., Gardiner, B., Hauf, Y., Jasinevičius, G., Labonne, S., Linkevičius, E., Mahnken, M., Milanovic, S., Nabuurs, G.-J., Nagel, T. A., Nikinmaa, L., Panyatov, M., Bercak, R., Seidl, R., Ostrogović Sever, M. Z., … Schelhaas, M.-J. (2023): Significant increase in natural disturbance impacts on European forests since 1950. *Global Change Biology*, *29*(5), 1359–1376. URL: https://doi.org/10.1111/gcb.16531

Paustian, M. & Theuvsen, L. (2017): Adoption of precision agriculture technologies by German crop farmers. *Precision Agriculture*, *18*(5), 701–716. URL: https://doi.org/10.1007/s11119-016-9482-5

Pe'er, G., Bonn, A., Bruelheide, H., Dieker, P., Eisenhauer, N., Feindt, P. H., Hagedorn, G., Hansjürgens, B., Herzon, I., Lomba, Â., Marquard, E., Moreira, F., Nitsch, H., Oppermann, R., Perino, A., Röder, N., Schleyer, C., Schindler, S., Wolf, C., … Lakner, S. (2020): Action needed for the EU Common Agricultural Policy to address sustainability challenges. *People and Nature*, *2*(2), 305–316. URL: https://doi.org/10.1002/pan3.10080

Pe'er, G., Zinngrebe, Y., Moreira, F., Sirami, C., Schindler, S., Müller, R., Bontzorlos, V., Clough, D., Bezák, P., Bonn, A., Hansjürgens, B., Lomba, A., Möckel, S., Passoni, G., Schleyer, C., Schmidt, J. & Lakner, S. (2019): A greener path for the EU Common Agricultural Policy. *Science*, *365*(6452), 449–451. URL: https://doi.org/10.1126/science.aax3146

Pendrill, F., Persson, U. M., Godar, J., Kastner, T., Moran, D., Schmidt, S. & Wood, R. (2019): Agricultural and forestry trade drives large share of tropical deforestation emissions. *Global Environmental Change*, *56*, 1–10. URL: https://doi.org/10.1016/j.gloenvcha.2019.03.002

Pérez, D. I., Fellmann, T., Weiss, F., Witzke, H. P., Barreiro, H. J., Himics, M., Jansson, T., Salputra, G. & Leip, A. (2016): *An Economic Assessment of GHG Mitigation Policy Options for EU Agriculture (EcAMPA 2)*. URL: https://doi.org/10.2791/843461

Pérez Domínguez, I., Fellmann, T., Witzke, P., Weiss, F., Hristov, J., Himics, M., Barreiro-Hurlé, J., Gómez-Barbero, M. & Leip, A. (2020): *Economic Assessment of GHG Mitigation Policy Options for EU Agriculture: A Closer Look at Mitigation Options and Regional Mitigation Costs (EcAMPA 3)*. URL: https://data.europa.eu/doi/10.2760/4668

Perpiña, C. C., Jacobs-Crisioni, C., Barranco, R., Curtale, R., Kompil, M., Vallecillo, S., Auteri, D. & Dijkstra, L. (2023): *Opportunities and Challenges for Remote Rural Areas in the European Union*. 14 November 2023. URL: https://publications.jrc.ec.europa.eu/repository/handle/JRC135398

Perpiña Castillo, C., Jacobs-Crisioni, C., Diogo, V. & Lavalle, C. (2021): Modelling agricultural land abandonment in a fine spatial resolution multi-level land-use model: An application for the EU. *Environmental Modelling & Software*, *136*. URL: https://doi.org/10.1016/j.envsoft.2020.104946

Phan-huy, C., Göswein, V. & Habert, G. (2023): Climate-effective use of straw in the EU bioeconomy: Comparing avoided and delayed emissions in the agricultural, energy and construction sectors. *Environmental Research Letters*, *18*(12). URL: https://doi.org/10.1088/1748-9326/ad0517

Pilli, R., Alkama, R., Cescatti, A., Kurz, W. A. & Grassi, G. (2022): The European forest carbon budget under future climate conditions and current management practices. *Biogeosciences*, *19*(13), 3263–3284. URL: https://doi.org/10.5194/bg-19-3263-2022

Pingoud, K., Ekholm, T., Sievänen, R., Huuskonen, S. & Hynynen, J. (2018): Trade-offs between forest carbon stocks and harvests in a steady state – A multi-criteria analysis. *Journal of Environmental Management*, *210*, 96–103. URL: https://doi.org/10.1016/j.jenvman.2017.12.076

Poeplau, C. & Don, A. (2015): Carbon sequestration in agricultural soils via cultivation of cover crops: A meta-analysis. *Agriculture, Ecosystems & Environment*, *200*, 33–41. URL: https://doi.org/10.1016/j.agee.2014.10.024

Poeplau, C., Don, A. & Schneider, F. (2021): Roots are key to increasing the mean residence time of organic carbon entering temperate agricultural soils. *Global Change Biology*, *27*(19), 4921–4934. URL: https://doi.org/10.1111/gcb.15787

Pollock, L. J., O'Connor, L. M. J., Mokany, K., Rosauer, D. F., Talluto, M. V. & Thuiller, W. (2020): Protecting Biodiversity (in All Its Complexity): New Models and Methods. *Trends in Ecology & Evolution*, *35*(12), 1119–1128. URL: https://doi.org/10.1016/j.tree.2020.08.015

Popkin, B. M., Corvalan, C. & Grummer-Strawn, L. M. (2020): Dynamics of the double burden of malnutrition and the changing nutrition reality. *The Lancet*, *395*(10217), 65–74. URL: https://doi.org/10.1016/S0140-6736(19)32497-3

Popp, J., Pető, K. & Nagy, J. (2013): Pesticide productivity and food security: A review. *Agronomy for Sustainable Development*, *33*(1), 243–255. URL: https://doi.org/10.1007/s13593-012-0105-x

Poux, X. & Aubert, P.-M. (2018): *An agroecological Europe in 2050: Multifunctional agriculture for healthy eating*. IDDRI, Institute for Sustainable Development and International Relations. URL: https://www.iddri.org/en/publications-and-events/study/agroecological-europe-2050-multifunctional-agriculture-healthy-eating

Poux, X. & Aubert, P.-M. (2022): Putting permanent grassland at the heart of a European agroecological transition: Findings and questions arising from the 'Ten Years for Agroecology' (TYFA) scenario. *Grass and Forage Science*, *77*(4), 257–269. URL: https://doi.org/10.1111/gfs.12597

Prăvălie, R., Patriche, C., Borrelli, P., Panagos, P., Roșca, B., Dumitraşcu, M., Nita, I.-A., Săvulescu, I., Birsan, M.-V. & Bandoc, G. (2021): Arable lands under the pressure of multiple land degradation processes. A global perspective. *Environmental Research*, *194*. URL: https://doi.org/10.1016/j.envres.2020.110697

Qiang, W., Niu, S., Liu, A., Kastner, T., Bie, Q., Wang, X. & Cheng, S. (2020): Trends in global virtual land trade in relation to agricultural products. *Land Use Policy*, *92*, 104439. URL: https://doi.org/10.1016/j.landusepol.2019.104439

Rakotomalala, A. A. N. A., Ficiciyan, A. M. & Tscharntke, T. (2023): Intercropping enhances beneficial arthropods and controls pests: A systematic review and meta-analysis. *Agriculture, Ecosystems & Environment*, *356*. URL: https://doi.org/10.1016/j.agee.2023.108617

Rasmussen, L. V., Grass, I., Mehrabi, Z., Smith, O. M., Bezner-Kerr, R., Blesh, J., Garibaldi, L. A., Isaac, M. E., Kennedy, C. M., Wittman, H., Batáry, P., Buchori, D., Cerda, R., Chará, J., Crowder, D. W., Darras, K., DeMaster, K., Garcia, K., Gómez, M., … Kremen, C. (2024): Joint environmental and social benefits from diversified agriculture. *Science*, *384*(6691), 87–93. URL: https://doi.org/10.1126/science.adj1914

Raven, P. H. & Wagner, D. L. (2021): Agricultural intensification and climate change are rapidly decreasing insect biodiversity. *Proceedings of the National Academy of Sciences*, *118*(2). URL: https://doi.org/10.1073/pnas.2002548117

Ray, D. K., Ramankutty, N., Mueller, N. D., West, P. C. & Foley, J. A. (2012): Recent patterns of crop yield growth and stagnation. *Nature Communications*, *3*(1), 1293. URL: https://doi.org/10.1038/ncomms2296

REFRESH (2019): *Pigs could stop 14 million tonnes of surplus food from being wasted: New research shows how this can be done safely. Press Release of the EU research project REFRESH*. URL: https://eu-refresh.org/sites/default/files/REFRESH%20press%20release%20-%20surplus%20food%20to%20pigs.pdf

Regan, J. T., Marton, S., Barrantes, O., Ruane, E., Hanegraaf, M., Berland, J., Korevaar, H., Pellerin, S. & Nesme, T. (2017): Does the recoupling of dairy and crop production via cooperation between farms generate environmental benefits? A case-study approach in Europe. *European Journal of Agronomy*, *82*, 342–356. URL: https://doi.org/10.1016/j.eja.2016.08.005

Régnier, E., Bolduc, N. & Aubert, P.-M. (2023): *Greening the agrifood system through the EU budget: Can we repurpose agricultural subsidies?* IDDRI, Institute for Sustainable Development and International Relations. URL: https://www.iddri.org/en/publications-and-events/issue-brief/greening-agrifood-system-through-eu-budget-can-we-repurpose

Reinsch, T., Loza, C., Malisch, C. S., Vogeler, I., Kluß, C., Loges, R. & Taube, F. (2021): Toward specialized or integrated systems in Northwest Europe: On-farm eco-efficiency of sairy farming in Germany. *Frontiers in Sustainable Food Systems*, *5*, 614348. URL: https://doi.org/10.3389/fsufs.2021.614348

Reus, J., Leendertse, P., Bockstaller, C., Fomsgaard, I., Gutsche, V., Lewis, K., Nilsson, C., Pussemier, L., Trevisan, M., van der Werf, H., Alfarroba, F., Blümel, S., Isart, J., McGrath, D. & Seppälä, T. (2002): Comparison and evaluation of eight pesticide environmental risk indicators developed in Europe and recommendations for future use. *Agriculture, Ecosystems & Environment*, *90*(2), 177–187. URL: https://doi.org/10.1016/S0167-8809(01)00197-9

Reyer, C. P. O., Bathgate, S., Blennow, K., Borges, J. G., Bugmann, H., Delzon, S., Faias, S. P., Garcia-Gonzalo, J., Gardiner, B., Gonzalez-Olabarria, J. R., Gracia, C., Hernández, J. G., Kellomäki, S., Kramer, K., Lexer, M. J., Lindner, M., van der Maaten, E., Maroschek, M., Muys, B., … Hanewinkel, M. (2017): Are forest disturbances amplifying or canceling out climate change-induced productivity changes in European forests? *Environmental Research Letters*, *12*(3), 034027. URL: https://doi.org/10.1088/1748-9326/aa5ef1

Rezaei, E. E., Webber, H., Asseng, S., Boote, K., Durand, J. L., Ewert, F., Martre, P. & MacCarthy, D. S. (2023): Climate change impacts on crop yields. *Nature Reviews Earth & Environment*, 1–16. URL: https://doi.org/10.1038/s43017-023-00491-0

Rezende, V. T., Ali, S., Bonaudo, T. & Gameiro, A. H. (2023): Brazilian soybeans as feed for livestock in Europe: An insight into the nitrogen flows. *Regional Environmental Change*, *23*(1), 33. URL: https://doi.org/10.1007/s10113-023-02034-1

Rigal, S., Dakos, V., Alonso, H., Auniņš, A., Benkő, Z., Brotons, L., Chodkiewicz, T., Chylarecki, P., de Carli, E., del Moral, J. C., Domşa, C., Escandell, V., Fontaine, B., Foppen, R., Gregory, R., Harris, S., Herrando, S., Husby, M., Ieronymidou, C., … Devictor, V. (2023): Farmland practices are driving bird population decline across Europe. *Proceedings of the National Academy of Sciences*, *120*(21). URL: https://doi.org/10.1073/pnas.2216573120

Riggers, C., Poeplau, C., Don, A., Frühauf, C. & Dechow, R. (2021): How much carbon input is required to preserve or increase projected soil organic carbon stocks in German croplands under climate change? *Plant and Soil*, *460*(1–2), 417–433. URL: https://doi.org/10.1007/s11104-020-04806-8

Roche, J. R., Berry, D. P., Delaby, L., Dillon, P. G., Horan, B., Macdonald, K. A. & Neal, M. (2018): Review: New considerations to refine breeding objectives of dairy cows for increasing robustness and sustainability of grass-based milk production systems. *Animal*, *12*(s2), s350–s362. URL: https://doi.org/10.1017/S1751731118002471

Rockström, J., Williams, J., Daily, G., Noble, A., Matthews, N., Gordon, L., Wetterstrand, H., DeClerck, F., Shah, M., Steduto, P., de Fraiture, C., Hatibu, N., Unver, O., Bird, J., Sibanda, L. & Smith, J. (2017): Sustainable intensification of agriculture for human prosperity and global sustainability. *Ambio*, *46*(1), 4–17. URL: https://doi.org/10.1007/s13280-016-0793-6

Röder, N. (2021): *Payments for the environment: New turmoil around an old issue*. CAP Reform. 2 March 2021. URL: https://capreform.eu/payments-for-the-environment-new-turmoil-around-an-old-issue/

Röder, N., Krämer, C., Grajewski, R., Lakner, S. & Matthews, A. (2024): What is the environmental potential of the post-2022 common agricultural policy? *Land Use Policy*, *144*. URL: https://doi.org/10.1016/j.landusepol.2024.107219

Rödl, A. (2017): Short rotation coppice: Status and prospects. In: R. A. Meyers (Ed.), *Encyclopedia of Sustainability Science and Technology*, 1–18. URL: https://doi.org/10.1007/978-1-4939-2493-6_988-1

Rojas-Downing, M. M., Nejadhashemi, A. P., Harrigan, T. & Woznicki, S. A. (2017): Climate change and livestock: Impacts, adaptation, and mitigation. *Climate Risk Management*, *16*, 145–163. URL: https://doi.org/10.1016/j.crm.2017.02.001

Rosa-Schleich, J., Loos, J., Mußhoff, O. & Tscharntke, T. (2019): Ecological-economic trade-offs of diversified farming systems: A review. *Ecological Economics*, *160*, 251–263. URL: https://doi.org/10.1016/j.ecolecon.2019.03.002

Rosenzweig, S. T., Carson, M. A., Baer, S. G. & Blair, J. M. (2016): Changes in soil properties, microbial biomass, and fluxes of C and N in soil following post-agricultural grassland restoration. *Applied Soil Ecology*, *100*, 186–194. URL: https://doi.org/10.1016/j.apsoil.2016.01.001

Rowe, R. L., Street, N. R. & Taylor, G. (2009): Identifying potential environmental impacts of large-scale deployment of dedicated bioenergy crops in the UK. *Renewable and Sustainable Energy Reviews*, *13*(1), 271–290. URL: https://doi.org/10.1016/j.rser.2007.07.008

Salbitano, F., Borelli, S., Conigliaro, M. & Chen, Y. (2016): *Guidelines on Urban and Peri-Urban Forestry*. FAO forestry paper 178. Food and Agriculture Organization of the United Nations. URL: https://openknowledge.fao.org/server/api/core/bitstreams/9c27d98b-8071-4ee7-8fc4-e0b430f8a8dc/content

Šálek, M., Hula, V., Kipson, M., Daňková, R., Niedobová, J. & Gamero, A. (2018): Bringing diversity back to agriculture: Smaller fields and non-crop elements enhance biodiversity in intensively managed arable farmlands. *Ecological Indicators*, *90*, 65–73. URL: https://doi.org/10.1016/j.ecolind.2018.03.001

Salliou, N. (2023): Quitting livestock farming: Transfarmation pathways and factors of change from post-livestock farmers' accounts. *Frontiers in Sustainable Food Systems*, *7*. URL: https://doi.org/10.3389/fsufs.2023.1122992

Sanchez Lopez, J., Caldeira, C., De Laurentiis, V., Sala, S. & Avraamides, M. (2020): *Brief on Food Waste in the European Union*. The European Commission's Knowledge Centre for Bioeconomy. URL: https://food.ec.europa.eu/document/download/d53de425-9468-4d56-82e0-f8d14a42ba28_en

Sandström, V., Chrysafi, A., Lamminen, M., Troell, M., Jalava, M., Piipponen, J., Siebert, S., van Hal, O., Virkki, V. & Kummu, M. (2022): Food system by-products upcycled in livestock and aquaculture feeds can increase global food supply. *Nature Food*, *3*(9), 729–740. URL: https://doi.org/10.1038/s43016-022-00589-6

San-Miguel-Ayanz, J., Durrant, T., Boca, R., Maianti, P., Libertà, G., Oom, D., Branco, A., Suarez-Moreno, M., Ferrari, D., Roglia, E., Scionti, N., De Rigo, D. & Broglia, M. (2023): *Forest fires in Europe, Middle East and North Africa 2022*. JRC, Joint Research Center. URL: https://data.europa.eu/doi/10.2760/348120

Santarius, T., Dencik, L., Diez, T., Ferreboeuf, H., Jankowski, P., Hankey, S., Hilbeck, A., Hilty, L. M., Höjer, M., Kleine, D., Lange, S., Pohl, J., Reisch, L., Ryghaug, M., Schwanen, T. & Staab, P. (2023): Digitalization and sustainability: A call for a digital Green Deal. *Environmental Science & Policy*, *147*, 11–14. URL: https://doi.org/10.1016/j.envsci.2023.04.020

Sanye, M. E. & Sala, S. (2023): *Consumption footprint and domestic footprint: Assessing the environmental impacts of EU consumption and production – Life cycle assessment to support the European Green Deal*. European Commission, Joint Research Centre. URL: https://doi.org/10.2760/218540

Sathre, R. & Gustavsson, L. (2021): A lifecycle comparison of natural resource use and climate impact of biofuel and electric cars. *Energy*, *237*. URL: https://doi.org/10.1016/j.energy.2021.121546

Scarlat, N., Fahl, F., Dallemand, J.-F., Monforti, F. & Motola, V. (2018): A spatial analysis of biogas potential from manure in Europe. *Renewable and Sustainable Energy Reviews*, *94*, 915–930. URL: https://doi.org/10.1016/j.rser.2018.06.035

Scarlat, N., Fahl, F., Lugato, E., Monforti-Ferrario, F. & Dallemand, J. F. (2019): Integrated and spatially explicit assessment of sustainable crop residues potential in Europe. *Biomass and Bioenergy*, *122*, 257–269. URL: https://doi.org/10.1016/j.biombioe.2019.01.021

Scarlat, N., Martinov, M. & Dallemand, J.-F. (2010): Assessment of the availability of agricultural crop residues in the European Union: Potential and limitations for bioenergy use. *Waste Management*, *30*(10), 1889–1897. URL: https://doi.org/10.1016/j.wasman.2010.04.016

Schäfer, A. C., Boeing, H., Conrad, & Watzl, B. (2024): *Wissenschaftliche Grundlagen der lebensmittelbezogenen Ernährungsempfehlungen für Deutschland.* DGE Arbeitsgruppe Lebensmittelbezogene Ernährungsempfehlungen. URL: https://www.ernaehrungs-umschau.de/fileadmin/Ernaehrungs-Umschau/pdfs/pdf_2024/03_24/EU03_2024_M158_M166_Online.pdf

Schäffer, A., Filser, J., Frische, T., Gessner, M., Köck, W., Kratz, W., Liess, M., Nuppenau, E.-A., Roß-Nickoll, M., Schäfer, R. & Scheringer, M. (2018): *The Silent Spring: On the Need for Sustainable Plant Protection*. Leopoldina Discussion No. 16. German National Academy of Sciences Leopoldina. URL: https://www.leopoldina.org/uploads/tx_leopublication/2018_Diskussionspapier_Pflanzenschutzmittel_EN_02.pdf

Schaller, L., Kantelhardt, J. & Drösler, M. (2011): Cultivating the climate: Socio-economic prospects and consequences of climate-friendly peat land management in Germany. *Hydrobiologia*, *674*(1), 91–104. URL: https://doi.org/10.1007/s10750-011-0736-y

Scheid, A., McDonald, H., Bognar, J. & Tremblay, L.-L. (2023): *Carbon Farming Co-Benefits*. Ecologic Institute. URL: https://www.ecologic.eu/19040

Schier, F., Iost, S., Seintsch, B., Weimar, H. & Dieter, M. (2022): Assessment of possible production leakage from implementing the EU Biodiversity Strategy on forest product markets. *Forests*, *13*(8), 1225. URL: https://doi.org/10.3390/f13081225

Schils, R., Bufe, C., Rhymer, C. M., Francksen, R. M., Klaus, V. H., Abdalla, M., Milazzo, F., Lellei-Kovács, E., Berge, H. ten, Bertora, C., Chodkiewicz, A., Dămătîrcă, C., Feigenwinter, I., Fernández-Rebollo, P., Ghiasi, S., Hejduk, S., Hiron, M., Janicka, M., Pellaton, R., … Price, J. P. N. (2022): Permanent grasslands in Europe: Land use change and intensification decrease their multifunctionality. *Agriculture, Ecosystems & Environment*, *330*. URL: https://doi.org/10.1016/j.agee.2022.107891

Schils, R., Newell Price, P., Klaus, V., Tonn, B., Hejduk, S., Stypinski, P., Hiron, M., Fernández, P., Ravetto Enri, S., Lellei-Kovács, E., Annett, N., Markovic, B., Lively, F., Ten Berge, H., Smith, K., Forster-Brown, C., Jones, M., Buchmann, N., Janicka, M., … Korevaar, H. (2020): European permanent grasslands mainly threatened by abandonment, heat and drought, and conversion to temporary grassland. *Proceedings of the 28th General Meeting of the European Grassland Federation*, *25*, 553–555. URL: https://doi.org/10.3929/ethz-b-000448642

Schils, R., Olesen, J. E., Kersebaum, K.-C., Rijk, B., Oberforster, M., Kalyada, V., Khitrykau, M., Gobin, A., Kirchev, H., Manolova, V., Manolov, I., Trnka, M., Hlavinka, P., Palosuo, T., Peltonen-Sainio, P., Jauhiainen, L., Lorgeou, J., Marrou, H., Danalatos, N., …

van Ittersum, M. K. (2018): Cereal yield gaps across Europe. *European Journal of Agronomy*, *101*, 109–120. URL: https://doi.org/10.1016/j.eja.2018.09.003

Schneider, K., Barreiro-Hurle, J. & Rodriguez-Cerezo, E. (2023a): Pesticide reduction amidst food and feed security concerns in Europe. *Nature Food*, *4*(9), 746–750. URL: https://doi.org/10.1038/s43016-023-00834-6

Schneider, M., Schelte, T., Schmitz, F. & Körner, M. (2023b): EuroCrops: The largest harmonized open crop dataset across the European Union. *Scientific Data*, *10*(1), 612. URL: https://doi.org/10.1038/s41597-023-02517-0

Schulte-Uebbing, L. & de Vries, W. (2021): Reconciling food production and environmental boundaries for nitrogen in the European Union. *Science of The Total Environment*, *786*. URL: https://doi.org/10.1016/j.scitotenv.2021.147427

Schwieger, S., Kreyling, J., Couwenberg, J., Smiljanić, M., Weigel, R., Wilmking, M. & Blume-Werry, G. (2021): Wetter is better: Rewetting of minerotrophic peatlands increases plant production and moves them towards carbon sinks in a dry year. *Ecosystems*, *24*(5), 1093–1109. URL: https://doi.org/10.1007/s10021-020-00570-z

Scown, M. W., Brady, M. V. & Nicholas, K. A. (2020): Billions in misspent EU agricultural subsidies could support the Sustainable Development Goals. *One Earth*, *3*(2), 237–250. URL: https://doi.org/10.1016/j.oneear.2020.07.011

Searchinger, T., James, O. & Dumas, P. (2022): *Europe's Land Future? Opportunities to use Europe's land to fight climate change and improve biodiversity—And why proposed policies could undermine both*. Center for Policy Research on Energy and Environment. URL: https://searchinger.princeton.edu/document/51

Sechi, V., Belle, J. van, Fritz, C., Tilak, A., Geurts, J., Roehrig, N., Nailon, P., Cartmell-Done, K., Liu, W., Smits, T., Boever, M. D., Ó´Brolcháin, N., Morley, T., Field, C., Kennedy, Johnson, Caporn, S., Halevy, C., Ryan, … Crushell, P. (2022): *Towards a Carbon Credit & Blue Credit Scheme for Peatlands. White Paper.* URL: https://vb.nweurope.eu/media/19605/carbon-blue-credit-white-paper-january-2023.pdf

Seidl, R., Thom, D., Kautz, M., Martin-Benito, D., Peltoniemi, M., Vacchiano, G., Wild, J., Ascoli, D., Petr, M., Honkaniemi, J., Lexer, M. J., Trotsiuk, V., Mairota, P., Svoboda, M., Fabrika, M., Nagel, T. A. & Reyer, C. P. O. (2017): Forest disturbances under climate change. *Nature Climate Change*, *7*, 395–402. URL: https://doi.org/10.1038/nclimate3303

Selivanov, E., Cudlín, P. & Horáček, P. (2023): Carbon neutrality of forest biomass for bioenergy: A scoping review. *iForest – Biogeosciences and Forestry*, *16*(2), 70–77. URL: https://doi.org/10.3832/ifor4160-015

Senapati, N. & Semenov, M. A. (2020): Large genetic yield potential and genetic yield gap estimated for wheat in Europe. *Global Food Security*, *24*. URL: https://doi.org/10.1016/j.gfs.2019.100340

Seobi, T., Anderson, S. H., Udawatta, R. P. & Gantzer, C. J. (2005): Influence of grass and agroforestry buffer strips on soil hydraulic properties for an albaqualf. *Soil Science Society of America Journal*, *69*(3), 893–901. URL: https://doi.org/10.2136/sssaj2004.0280

Šestak, M. & Copot, D. (2023): Towards trusted data sharing and exchange in agro-food supply chains: Design principles for agricultural data spaces. *Sustainability*, *15*(18), 13746. URL: https://doi.org/10.3390/su151813746

Shurson, G. C., Dierenfeld, E. S. & Dou, Z. (2023): Rules are meant to be broken: Rethinking the regulations on the use of food waste as animal feed. *Resources, Conservation and Recycling*, *199*, 107273. URL: https://doi.org/10.1016/j.resconrec.2023.107273

Silanikove, N. (2000): Effects of heat stress on the welfare of extensively managed domestic ruminants. *Livestock Production*

Science, *67*(1–2), 1–18. URL: https://doi.org/10.1016/S0301-6226(00)00162-7

Simon, P. L., Dieckow, J., Zanatta, J. A., Ramalho, B., Ribeiro, R. H., van der Weerden, T. & de Klein, C. A. M. (2020): Does Brachiaria humidicola and dicyandiamide reduce nitrous oxide and ammonia emissions from cattle urine patches in the subtropics? *The Science of the Total Environment*, *720*, 137692. URL: https://doi.org/10.1016/j.scitotenv.2020.137692

Singh, B. K., Delgado-Baquerizo, M., Egidi, E., Guirado, E., Leach, J. E., Liu, H. & Trivedi, P. (2023): Climate change impacts on plant pathogens, food security and paths forward. *Nature Reviews Microbiology*, *21*(10), 640–656. URL: https://doi.org/10.1038/s41579-023-00900-7

Sinke, P., Swartz, E., Sanctorum, H., van der Giesen, C. & Odegard, I. (2023): Ex-ante life cycle assessment of commercial-scale cultivated meat production in 2030. *The International Journal of Life Cycle Assessment*, *28*(3), 234–254. URL: https://doi.org/10.1007/s11367-022-02128-8

Sirami, C., Gross, N., Baillod, A. B., Bertrand, C., Carrié, R., Hass, A., Henckel, L., Miguet, P., Vuillot, C., Alignier, A., Girard, J., Batáry, P., Clough, Y., Violle, C., Giralt, D., Bota, G., Badenhausser, I., Lefebvre, G., Gauffre, B., … Fahrig, L. (2019): Increasing crop heterogeneity enhances multitrophic diversity across agricultural regions. *Proceedings of the National Academy of Sciences of the United States of America*, *116*(33), 16442–16447. URL: https://doi.org/10.1073/pnas.1906419116

SMEKUL (Sächsisches Staatsministerium für Energie, Klimaschutz, Umwelt und Landwirtschaft) (2021): *Mehr Regio- und Bio-Regio-Produkte in der Gemeinschaftsverpflegung: Handreichung zur Arbeitshilfe für Vergabestellen*. URL: https://www.landwirtschaft.sachsen.de/download/HandreichungSachsenMLB_bf.pdf

Smith et al. (2024): *The State of Carbon Dioxide Removal 2024. 2nd Edition*. URL: https://www.stateofcdr.org

Snyder, K. A., Miththapala, S., Sommer, R. & Braslow, J. (2017): The yield gap: Closing the gap by widening the approach. *Experimental Agriculture*, *53*(3), 445–459. URL: https://doi.org/10.1017/S0014479716000508

Soimakallio, S., Böttcher, H., Niemi, J., Mosley, F., Turunen, S., Hennenberg, K. J., Reise, J. & Fehrenbach, H. (2022): Closing an open balance: The impact of increased tree harvest on forest carbon. *GCB Bioenergy*, *14*(8), 989–1000. URL: https://doi.org/10.1111/gcbb.12981

Soimakallio, S., Kalliokoski, T., Lehtonen, A. & Salminen, O. (2021): On the trade-offs and synergies between forest carbon sequestration and substitution. *Mitigation and Adaptation Strategies for Global Change*, *26*(1), 4. URL: https://doi.org/10.1007/s11027-021-09942-9

Soley, F. G. & Perfecto, I. (2021): A way forward for biodiversity conservation: High-quality landscapes. *Trends in Ecology & Evolution*, *36*(9), 770–773. URL: https://doi.org/10.1016/j.tree.2021.04.012

Soto-Navarro, C. A., Harfoot, M., Hill, S. L. L., Campbell, J., Mora, F., Campos, C., Pretorius, C., Pascual, U., Kapos, V., Allison, H. & Burgess, N. D. (2021): Towards a multidimensional biodiversity index for national application. *Nature Sustainability*, *4*(11), 933–942. URL: https://doi.org/10.1038/s41893-021-00753-z

Souza, G. M., Ballester, M. V. R., de Brito Cruz, C. H., Chum, H., Dale, B., Dale, V. H., Fernandes, E. C. M., Foust, T., Karp, A., Lynd, L., Maciel Filho, R., Milanez, A., Nigro, F., Osseweijer, P., Verdade, L. M., Victoria, R. L. & Van der Wielen, L. (2017): The role of bioenergy in a climate-changing world. *Environmental Development*, *23*, 57–64. URL: https://doi.org/10.1016/j.envdev.2017.02.008

Spiller, A. & Kühl, S. (2022): Pathways to finance a socially accepted animal husbandry. *Journal of Consumer Protection and Food Safety*, *17*(2), 109–111. URL: https://doi.org/10.1007/s00003-022-01378-w

Springmann, M., Clark, M. A., Rayner, M., Scarborough, P. & Webb, P. (2021): The global and regional costs of healthy and sustainable dietary patterns: A modelling study. *The Lancet Planetary Health*, *5*(11). URL: https://doi.org/10.1016/S2542-5196(21)00251-5

Springmann, M., Clark, M., Mason-D'Croz, D., Wiebe, K., Bodirsky, B. L., Lassaletta, L., de Vries, W., Vermeulen, S. J., Herrero, M., Carlson, K. M., Jonell, M., Troell, M., DeClerck, F., Gordon, L. J., Zurayk, R., Scarborough, P., Rayner, M., Loken, B., Fanzo, J., … Willett, W. (2018): Options for keeping the food system within environmental limits. *Nature*, *562*(7728), 519–525. URL: https://doi.org/10.1038/s41586-018-0594-0

Statsministeriet (2022): *Regeringsgrundlag 2022*. URL: https://www.stm.dk/statsministeriet/publikationer/regeringsgrundlag-2022/

Stein, S. & Steinmann, H.-H. (2018): Identifying crop rotation practice by the typification of crop sequence patterns for arable farming systems: A case study from Central Europe. *European Journal of Agronomy*, *92*, 30–40. URL: https://doi.org/10.1016/j.eja.2017.09.010

Stepanyan, D., Heidecke, C., Osterburg, B. & Gocht, A. (2023): Impacts of national vs European carbon pricing on agriculture. *Environmental Research Letters*, *18*(7), 074016. URL: https://doi.org/10.1088/1748-9326/acdcac

Stoessel, F., Juraske, R., Pfister, S. & Hellweg, S. (2012): Life cycle inventory and carbon and water foodprint of fruits and vegetables: Application to a Swiss retailer. *Environmental Science & Technology*, *46*(6), 3253–3262. URL: https://doi.org/10.1021/es2030577

Suleiman, A. K. A., Gonzatto, R., Aita, C., Lupatini, M., Jacques, R. J. S., Kuramae, E. E., Antoniolli, Z. I. & Roesch, L. F. W. (2016): Temporal variability of soil microbial communities after application of dicyandiamide-treated swine slurry and mineral fertilizers. *Soil Biology and Biochemistry*, *97*, 71–82. URL: https://doi.org/10.1016/j.soilbio.2016.03.002

Sutton, M. A., Howard, C. M., Kanter, D. R., Lassaletta, L., Móring, A., Raghuram, N. & Read, N. (2021): The nitrogen decade: Mobilizing global action on nitrogen to 2030 and beyond. *One Earth*, *4*(1), 10–14. URL: https://doi.org/10.1016/j.oneear.2020.12.016

Swensson, L. F. J., Hunter, D., Schneider, S. & Tartanac, F. (2021): Public food procurement as a game changer for food system transformation. *The Lancet Planetary Health*, *5*(8), e495–e496. URL: https://doi.org/10.1016/S2542-5196(21)00176-5

Swinburn, B. A., Kraak, V. I., Allender, S., Atkins, V. J., Baker, P. I., Bogard, J. R., Brinsden, H., Calvillo, A., Schutter, O. D., Devarajan, R., Ezzati, M., Friel, S., Goenka, S., Hammond, R. A., Hastings, G., Hawkes, C., Herrero, M., Hovmand, P. S., Howden, M., … Dietz, W. H. (2019): The Global Syndemic of Obesity, Undernutrition, and Climate Change: The Lancet Commission report. *The Lancet*, *393*(10173), 791–846. URL: https://doi.org/10.1016/S0140-6736(18)32822-8

Swinburn, B. A., Sacks, G., Vandevijvere, S., Kumanyika, S., Lobstein, T., Neal, B., Barquera, S., Friel, S., Hawkes, C., Kelly, B., L'Abbé, M., Lee, A., Ma, J., Macmullan, J., Mohan, S., Monteiro, C., Rayner, M., Sanders, D., Snowdon, W., … Informas. (2013): INFORMAS (International Network for Food and Obesity/non-communicable diseases Research, Monitoring and Action Support): Overview and key principles. *Obesity Reviews*, *14*(S1), 1–12. URL: https://doi.org/10.1111/obr.12087

Tanneberger, F., Abel, S., Couwenberg, J., Dahms, T., Gaudig, G., Günther, A., Kreyling, J., Peters, J., Pongratz, J. & Joosten, H. (2021a): Towards net zero CO_2 in 2050: An emission reduction pathway for organic soils in Germany. *Mires and Peat*, *27*(05), 1–17. URL: https://doi.org/10.19189/MaP.2020.SNPG.StA.1951

Tanneberger, F., Appulo, L., Ewert, S., Lakner, S., Ó Brolcháin, N., Peters, J. & Wichtmann, W. (2021b): The Power of Nature-Based Solutions: How Peatlands Can Help Us to Achieve Key EU Sustainability Objectives. *Advanced Sustainable Systems*, *5*(1). URL: https://doi.org/10.1002/adsu.202000146

Tanneberger, F., Birr, F., Couwenberg, J., Kaiser, M., Luthardt, V., Nerger, M., Pfister, S., Oppermann, R., Zeitz, J., Beyer, C., van der Linden, S., Wichtmann, W. & Närmann, F. (2022): Saving soil carbon, greenhouse gas emissions, biodiversity and the economy: Paludiculture as sustainable land use option in German fen peatlands. *Regional Environmental Change*, *22*(2), 69. URL: https://doi.org/10.1007/s10113-022-01900-8

Taube, F., Nyameasem, J. K., Fenger, F., Alderkamp, L., Kluß, C. & Loges, R. (2023): Eco-efficiency of leys: The trigger for sustainable integrated crop-dairy farming systems. *Grass and Forage Science*. URL: https://doi.org/10.1111/gfs.12639

Tedesco, A. M., Brancalion, P. H. S., Hepburn, M. L. H. K., Walji, K., Wilson, K. A., Possingham, H. P., Dean, A. J., Nugent, N., Elias-Trostmann, K., Perez-Hammerle, K.-V. & Rhodes, J. R. (2023): The role of incentive mechanisms in promoting forest restoration. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *378*(1867), 20210088. URL: https://doi.org/10.1098/rstb.2021.0088

Tei, F., De Neve, S., de Haan, J. & Kristensen, H. L. (2020): Nitrogen management of vegetable crops. *Agricultural Water Management*, *240*. URL: https://doi.org/10.1016/j.agwat.2020.106316

Temmink, R. J. M., Robroek, B. J. M., Van Dijk, G., Koks, A. H. W., Käärmelahti, S. A., Barthelmes, A., Wassen, M. J., Ziegler, R., Steele, M. N., Giesen, W., Joosten, H., Fritz, C., Lamers, L. P. M. & Smolders, A. J. P. (2023): Wetscapes: Restoring and maintaining peatland landscapes for sustainable futures. *Ambio*, *52*(9), 1519–1528. URL: https://doi.org/10.1007/s13280-023-01875-8

Tetteh, G. O., Gocht, A., Erasmi, S., Schwieder, M. & Conrad, C. (2021): Evaluation of Sentinel-1 and Sentinel-2 feature sets for delineating agricultural fields in heterogeneous landscapes. *IEEE Access*, *9*, 116702–116719. URL: https://doi.org/10.1109/ACCESS.2021.3105903

Thies, C. & Tscharntke, T. (1999): Landscape structure and biological control in agroecosystems. *Science*, *285*(5429), 893–895. URL: https://doi.org/10.1126/science.285.5429.893

Thompson, I., Mackey, B., Mcnulty, S. & Mosseler, A. (2009): *Forest resilience, biodiversity, and climate change: A synthesis of the biodiversity/resilience/stability relationship in forest ecosystems.* CBD Technical Series No. 43. Secretariat of the Convention on Biological Diversity. URL: https://www.cbd.int/doc/publications/cbd-ts-43-en.pdf

Thompson, R. B., Incrocci, L., van Ruijven, J. & Massa, D. (2020): Reducing contamination of water bodies from European vegetable production systems. *Agricultural Water Management*, *240*. URL: https://doi.org/10.1016/j.agwat.2020.106258

Thornton, P., Nelson, G., Mayberry, D. & Herrero, M. (2021): Increases in extreme heat stress in domesticated livestock species during the twenty-first century. *Global Change Biology*, *27*(22), 5762–5772. URL: https://doi.org/10.1111/gcb.15825

Trinomics B.V. (2023): *Pricing Agricultural Emissions and Rewarding Climate Action in the Agri-food Value Chain*. URL: https://climate.ec.europa.eu/document/996c24d8-9004-4c4e-b637-60b384ae4814_en

Tscharntke, T. & Batáry, P. (2023): Agriculture, urbanization, climate, and forest change drive bird declines. *Proceedings of the National Academy of Sciences*, *120*(22). URL: https://doi.org/10.1073/pnas.2305216120

Tscharntke, T., Batáry, P. & Grass, I. (2024): Mixing on- and off-field measures for biodiversity conservation. *Trends in Ecology & Evolution*. URL: https://doi.org/10.1016/j.tree.2024.04.003

Tscharntke, T., Grass, I., Wanger, T. C., Westphal, C. & Batáry, P. (2021): Beyond organic farming: Harnessing biodiversity-friendly landscapes. *Trends in Ecology & Evolution*, *36*(10), 919–930. URL: https://doi.org/10.1016/j.tree.2021.06.010

Tscharntke, T., Grass, I., Wanger, T. C., Westphal, C. & Batáry, P. (2022): Prioritise the most effective measures for biodiversity-friendly agriculture. *Trends in Ecology & Evolution*, *37*(5), 397–398. URL: https://doi.org/10.1016/j.tree.2022.02.008

Tscharntke, T., Klein, A. M., Kruess, A., Steffan-Dewenter, I. & Thies, C. (2005): Landscape perspectives on agricultural intensification and biodiversity: Ecosystem service management. *Ecology Letters*, *8*(8), 857–874. URL: https://doi.org/10.1111/j.1461-0248.2005.00782.x

Tscharntke, T., Tylianakis, J. M., Rand, T. A., Didham, R. K., Fahrig, L., Batáry, P., Bengtsson, J., Clough, Y., Crist, T. O., Dormann, C. F., Ewers, R. M., Fründ, J., Holt, R. D., Holzschuh, A., Klein, A. M., Kleijn, D., Kremen, C., Landis, D. A., Laurance, W., … Westphal, C. (2012): Landscape moderation of biodiversity patterns and processes: Eight hypotheses. *Biological Reviews of the Cambridge Philosophical Society*, *87*(3), 661–685. URL: https://doi.org/10.1111/j.1469-185X.2011.00216.x

Tsiafouli, M. A., Thébault, E., Sgardelis, S. P., de Ruiter, P. C., van der Putten, W. H., Birkhofer, K., Hemerik, L., de Vries, F. T., Bardgett, R. D., Brady, M. V., Bjornlund, L., Jørgensen, H. B., Christensen, S., Hertefeldt, T. D., Hotes, S., Gera Hol, W. h., Frouz, J., Liiri, M., Mortimer, S. R., … Hedlund, K. (2015): Intensive agriculture reduces soil biodiversity across Europe. *Global Change Biology*, *21*(2), 973–985. URL: https://doi.org/10.1111/gcb.12752

Umweltbundesamt (2016): *Förderung des Waldumbaus*. URL: https://www.umweltbundesamt.de/monitoring-zur-das/handlungsfelder/wald-und-forstwirtschaft/fw-r-1/indikator

UN General Assembly (United Nations General Assembly) (2015): *Transforming our World: The 2030 Agenda for Sustainable Development.* Department of Economic and Social Affairs. URL: https://sdgs.un.org/2030agenda

UNEP (United Nations Environment Programme) (2020a): *Healthy Food for All: How do We Make Healthy Diets Accessible and Affordable for All? A Framework for Action.* Perspectives Issue No. 39. URL: https://wedocs.unep.org/handle/20.500.11822/34434

UNEP (United Nations Environment Programme) (2020b): *Preventing the Next Pandemic: Zoonotic Diseases and How to Break the Chain of Transmission*. URL: https://www.unep.org/resources/report/preventing-future-zoonotic-disease-outbreaks-protecting-environment-animals-and

UNEP (United Nations Environment Programme) (2022): *Global Peatlands Assessment: The State of the World's Peatlands. Evidence for action toward the conservation, restoration, and sustainable management of peatlands. Main Report.* URL: https://www.unep.org/resources/global-peatlands-assessment-2022

UNEP (United Nations Environment Programme) (2024): *UNEP Food Waste Index Report 2024: Key Messages*. URL: https://www.unep.org/resources/publication/food-waste-index-report-2024

UNFCCC (United Nations Framework Convention on Climate Change) (2015): *Report of the Conference of the Parties on its twenty-first session, held in Paris from 30 November to 13 December 2015. Addendum. Part two: Action taken by the Conference of the Parties at its twenty-first session.* URL: https://unfccc.int/documents/9097

University of Greifswald, University of Warsaw, University of Antwerp, University of Vienna, Norwegian Institute for Nature Research & Natural Resources Institute Finland (2022): *Position on the Role of Peatland Conservation, Rewetting and Restoring within the Carbon Removal Certification Framework Proposed by the European Commission. Position Paper.* URL: https://www.greifswaldmoor.de/files/dokumente/Infopapiere_Briefings/202205_Positionpaper_call%20for%20evidence_carbon%20removal%20certification_PRINCESS_final.pdf

Vacek, Z., Vacek, S. & Cukor, J. (2023): European forests under global climate change: Review of tree growth processes, crises and management strategies. *Journal of Environmental Management*, *332*, 117353. URL: https://doi.org/10.1016/j.jenvman.2023.117353

van Apeldoorn, D., Norén, I. S., Ditzler, L. & Rossing, W. (2020): *Designing strip intercropping systems*. Agricology. URL: https://agricology.co.uk/resource/designing-strip-intercropping-systems/

van den Pol-van Dasselaar, A., Becker, T., Fernández, A. & Peratoner, G. (2021): Societal and economic options to support grassland-based dairy production in Europe. *Irish Journal of Agricultural and Food Research*, *59*. URL: https://doi.org/10.15212/ijafr-2020-0128

van der Werf, W., Keesman, K., Burgess, P., Graves, A., Pilbeam, D., Incoll, L. D., Metselaar, K., Mayus, M., Stappers, R., Van Keulen, H., Palma, J. & Dupraz, C. (2007): Yield-SAFE: A parameter-sparse, process-based dynamic model for predicting resource capture, growth, and production in agroforestry systems. *Ecological Engineering*, *29*(4), 419–433. URL: https://doi.org/10.1016/j.ecoleng.2006.09.017

van Dijk, W. F. A., Lokhorst, A. M., Berendse, F. & de Snoo, G. R. (2015): Collective agri-environment schemes: How can regional environmental cooperatives enhance farmers' intentions for agri-environment schemes? *Land Use Policy*, *42*, 759–766. URL: https://doi.org/10.1016/j.landusepol.2014.10.005

van Ittersum, M. K. & Cassman, K. G. (2013): Yield gap analysis: Rationale, methods and applications. Introduction to the Special Issue. *Field Crops Research*, *143*, 1–3. URL: https://doi.org/10.1016/j.fcr.2012.12.012

Van Zalk, J. & Behrens, P. (2018): The spatial extent of renewable and non-renewable power generation: A review and meta-analysis of power densities and their application in the U.S. *Energy Policy*, *123*, 83–91. URL: https://doi.org/10.1016/j.enpol.2018.08.023

Vanbeveren, S. P. P. & Ceulemans, R. (2019): Biodiversity in short-rotation coppice. *Renewable and Sustainable Energy Reviews*, *111*, 34–43. URL: https://doi.org/10.1016/j.rser.2019.05.012

Vargas, J., Ungerfeld, E., Muñoz, C. & DiLorenzo, N. (2022): Feeding strategies to mitigate enteric methane emission from ruminants in grassland systems. *Animals*, *12*(9), 1132. URL: https://doi.org/10.3390/ani12091132

Verbraucherzentrale Niedersachsen e. V. (2022): *Obst und Gemüse im Einzelhandel. Qualitätsanforderungen und Lebensmittelverschwendung: Marktcheck der Verbraucherzentralen*. URL: https://www.verbraucherzentrale.de/sites/default/files/2022-01/verbraucherzentrale-marktcheck-obst-und-gemuese-2022.pdf

Vinceti, B., Manica, M., Lauridsen, N., Verkerk, P. J., Lindner, M. & Fady, B. (2020): Managing forest genetic resources as a strategy to adapt forests to climate change: Perceptions of European forest owners and managers. *European Journal of Forest Research*, *139*(6), 1107–1119. URL: https://doi.org/10.1007/s10342-020-01311-6

Visser, O., Sippel, S. R. & Thiemann, L. (2021): Imprecision farming? Examining the (in)accuracy and risks of digital agriculture. *Journal of Rural Studies*, *86*, 623–632. URL: https://doi.org/10.1016/j.jrurstud.2021.07.024

Vizzarri, M., Pilli, R., Korosuo, A., Frate, L. & Grassi, G. (2022): The role of forests in climate change mitigation: The EU context. In: R. Tognetti, M. Smith & P. Panzacchi (Eds.), *Climate-Smart Forestry in Mountain Regions,* 507–520. URL: https://link.springer.com/10.1007/978-3-030-80767-2_15

Vogeler, I., Böldt, M. & Taube, F. (2022): Mineralisation of catch crop residues and N transfer to the subsequent crop. *Science of The Total Environment*, *810*. URL: https://doi.org/10.1016/j.scitotenv.2021.152142

von Behr, W., Bemmann, A., Michalk, K., Große, W., Ehm, T. & Gerdes, G. (2012): *Kurzumtriebsplantagen: Anlage, Pflege, Ernte und Wertschöpfung*. URL: https://www.dlg.org/de/landwirtschaft/themen/bioenergie/forstwirtschaft/dlg-merkblatt-371

von Unger, M., Emmer, I., Joosten, H. & Couwenberg, J. (2019): *Designing an International Peatland Carbon Standard: Criteria, Best Practices and Opportunities. Final Report*. Umweltbundesamt. URL: https://www.umweltbundesamt.de/sites/default/files/medien/1410/publikationen/2019-11-28_cc-42-2019_sca_peatland_standards_0.pdf

vonHedemann, N., Wurtzebach, Z., Timberlake, T. J., Sinkular, E. & Schultz, C. A. (2020): Forest policy and management approaches for carbon dioxide removal. *Interface Focus*, *10*(5). URL: https://doi.org/10.1098/rsfs.2020.0001

Vroege, W., Dalhaus, T., Wauters, E. & Finger, R. (2023): Effects of extreme heat on milk quantity and quality. *Agricultural Systems*, *210*, 103731. URL: https://doi.org/10.1016/j.agsy.2023.103731

Wallace, T. C., Bailey, R. L., Blumberg, J. B., Burton-Freeman, B., Chen, C.-Y. O., Crowe-White, K. M., Drewnowski, A., Hooshmand, S., Johnson, E., Lewis, R., Murray, R., Shapses, S. A. & Wang, D. D. (2020): Fruits, vegetables, and health: A comprehensive narrative, umbrella review of the science and recommendations for enhanced public policy to improve intake. *Critical Reviews in Food Science and Nutrition*, *60*(13), 2174–2211. URL: https://doi.org/10.1080/10408398.2019.1632258

Walpole, S. C., Prieto-Merino, D., Edwards, P., Cleland, J., Stevens, G. & Roberts, I. (2012): The weight of nations: An estimation of adult human biomass. *BMC Public Health*, *12*(1), 439. URL: https://doi.org/10.1186/1471-2458-12-439

Walter, A., Finger, R., Huber, R. & Buchmann, N. (2017): Smart farming is key to developing sustainable agriculture. *Proceedings of the National Academy of Sciences*, *114*(24), 6148–6150. URL: https://doi.org/10.1073/pnas.1707462114

Walton, S. (2023): *Linking middle-chain actors to the environmental impacts of food producers and consumers: Underlying drivers and policy implications*. Centre for Food Policy, City University London. URL: https://researchcentres.city.ac.uk/__data/assets/pdf_file/0005/723695/CFP_Linking-MiddleChain.pdf

Wang, Y., de Boer, I. J. M., Persson, U. M., Ripoll-Bosch, R., Cederberg, C., Gerber, P. J., Smith, P. & van Middelaar, C. E. (2023): Risk to rely on soil carbon sequestration to offset global ruminant emissions. *Nature Communications*, *14*(1), 7625. URL: https://doi.org/10.1038/s41467-023-43452-3

WBAE (Scientific Advisory Board on Agricultural Policy, Food and Consumer Health Protection at the Federal Ministry of Food and Agriculture) (2015): *Pathways to a socially accepted livestock husbandry in Germany. Executive summary and synthesis report*. URL: https://www.bmel.de/SharedDocs/Downloads/EN/_Ministry/ScientificAdvisoryBoard-Pathways.pdf

WBAE (Scientific Advisory Board on Agricultural Policy, Food and Consumer Health Protection at the Federal Ministry of Food and Agriculture) (2018): *For an EU Common Agricultural Policy serving the public good after 2020: Fundamental questions and recommendations. Report*. URL: https://www.bmel.de/SharedDocs/Downloads/EN/_Ministry/AgriculturalPolicy-after2020-report.pdf

WBAE (Scientific Advisory Board on Agricultural Policy, Food and Consumer Health Protection at the Federal Ministry of Food and Agriculture) (2019): *Designing an effective agri-environment-climate policy as part of the post-2020 EU Common Agricultural Policy*. URL: https://www.bmel.de/SharedDocs/Downloads/EN/_Ministry/agri-environment-climate-post-2020.pdf

WBAE (Scientific Advisory Board on Agricultural Policy, Food and Consumer Health Protection at the Federal Ministry of Food and Agriculture) (2020): *Promoting sustainability in food consumption. Developing an integrated food policy and creating fair food environments*. URL: https://www.bmel.de/SharedDocs/Downloads/EN/_Ministry/Scientific_Advisory_Board-Promoting-sustainability-food-consumption.pdf

WBAE (Scientific Advisory Board on Agricultural Policy, Food and Consumer Health Protection at the Federal Ministry of Food and Agriculture) (2023): *New due diligence obligations for companies in the agri-food sector: Recommendations on current legislative developments. Preliminary translation Version dated 8 December 2023*. URL: https://www.bmel.de/SharedDocs/Downloads/EN/_Ministry/New-due-diligence-obligation-for-companies.html

WBAE (Scientific Advisory Board on Agricultural Policy, Food and Consumer Health Protection at the Federal Ministry of Food and Agriculture) & WBW (Scientific Advisory Board on Forest Policy at the Federal Ministry of Food and Agriculture) (2016): *Climate change mitigation in agriculture and forestry and in the downstream sectors of food and timber use. Executive Summary*. URL: https://www.bmel.de/SharedDocs/Downloads/EN/_Ministry/ClimateChangeMitigation.pdf

WBD (Scientific Advisory Board on Fertiliser Issues at the Federal Ministry of Food and Agriculture) (2024): *Biokohle in der Pflanzenproduktion: Nutzen, Grenzen und Zielkonflikte. Standpunkt des Wissenschaftlichen Beirats für Düngungsfragen*. URL: https://www.bmel.de/SharedDocs/Downloads/DE/_Ministerium/Beiraete/duengung/biokohle-pflanzenproduktion.pdf

Wegener, J. K., Urso, L.-M., von Hörsten, D., Hegewald, H., Minßen, T.-F., Schattenberg, J., Gaus, C.-C., de Witte, T., Nieberg, H., Isermeyer, F., Frerichs, L. & Backhaus, G. F. (2019): Spot farming: An alternative for future plant production. *Journal of Cultivated Plants*, *71*(4), 70. URL: https://doi.org/10.5073/JfK.2019.04.02

Weißhuhn, P., Reckling, M., Stachow, U. & Wiggering, H. (2017): Supporting agricultural ecosystem services through the integration of perennial polycultures into crop rotations. *Sustainability*, *9*(12), 2267. URL: https://doi.org/10.3390/su9122267

Westerink, J., Jongeneel, R., Polman, N., Prager, K., Franks, J., Dupraz, P. & Mettepenningen, E. (2017): Collaborative governance arrangements to deliver spatially coordinated agri-environmental management. *Land Use Policy*, *69*, 176–192. URL: https://doi.org/10.1016/j.landusepol.2017.09.002

Westhoek, H. J., Overmars, K. P. & van Zeijts, H. (2013): The provision of public goods by agriculture: Critical questions for effective and efficient policy making. *Environmental Science & Policy*, *32*, 5–13. URL: https://doi.org/10.1016/j.envsci.2012.06.015

WHO (World Health Organization) (2013): *NCD Global Monitoring Framework*. URL: https://www.who.int/publications-detail-redirect/ncd-surveillance-global-monitoring-framework

WHO (World Health Organization) (2019): *Healthy, prosperous lives for all: The European Health Equity Status Report*. URL: https://www.who.int/publications-detail-redirect/9789289054256

WHO (World Health Organization) (2021): *Tripartite and UNEP support OHHLEP's definition of 'One Health'. Joint Tripartite (FAO, OIE, WHO) and UNEP Statement*. URL: https://www.who.int/news/item/01-12-2021-tripartite-and-unep-support-ohhlep-s-definition-of-one-health

WHO (World Health Organization) (2022): *Food marketing exposure and power and their associations with food-related attitudes, beliefs and behaviours: A narrative review*. URL: https://www.who.int/publications-detail-redirect/9789240041783

WHO European Region (2018): *Evaluating implementation of the WHO set of recommendations on the marketing of foods and non-alcoholic beverages to children: Progress, challenges and guidance for next steps in the WHO European Region.* URL: https://oro.open.ac.uk/57150/1/WHO 2018 Current regulations%2C loopholes%2C challenges in Europe against junk food marketing.pdf

WHO European Region (World Health Organization) (2022): *WHO European Regional Obesity Report 2022*. URL: https://apps.who.int/iris/handle/10665/353747

WHO European Region (World Health Organization) (2023): *The Diet Impact Assessment model: A tool for analyzing the health, environmental and affordability implications of dietary change*. URL: https://www.who.int/europe/publications/i/item/WHO-EURO-2023-8349-48121-71370

Wichmann, S. (2018): *Economic incentives for climate smart agriculture on peatlands in the EU*. Proceedings of the Greifswald Mire Centre 01/2018. URL: https://greifswaldmoor.de/files/dokumente/GMC%20Schriften/Report_Economic%20incentives_Cinderella_GMC%20Proceedings_web.pdf

Wichmann, S., Nordt, A. & Schäfer, A. (2022a): *Lösungsansätze zum Erreichen der Klimaschutzziele und Kosten für die Umstellung auf Paludikultur. Hintergrundpapier zur Studie „Anreize für Paludikultur zur Umsetzung der Klimaschutzziele 2030 und 2050“*. Deutsche Emissionshandelsstelle. URL: https://www.dehst.de/SharedDocs/downloads/DE/projektmechanismen/Hintergrundpapier-loesungsansaetze-paludikultur.pdf

Wichmann, S., Reichelt, F. & Nordt, A. (2022b): *Herleitung von Förderpauschalen zur Umsetzung von Moorklimaschutzprojekten.* Greifswald Moor Centrum-Schriftenreihe 01/2022. URL: https://www.greifswaldmoor.de/files/dokumente/GMC%20Schriften/2022-01_Wichmann%20et%20al_Herleitung%20von%20F%C3%B6rderpauschalen%20zur%20Umsetzung%20von%20Moorklimaschutzprojekten.pdf

Willett, W., Rockström, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S., Garnett, T., Tilman, D., DeClerck, F., Wood, A., Jonell, M., Clark, M., Gordon, L. J., Fanzo, J., Hawkes, C., Zurayk, R., Rivera, J. A., de Vries, W., Sibanda, L. M., … Murray, C. J. L. (2019): Food in the Anthropocene: The EAT-Lancet Commission on healthy diets from sustainable food systems. *The Lancet*, *393*(10170), 447–492. URL: https://doi.org/10.1016/S0140-6736(18)31788-4

Wilson, D., Blain, D., Couwenberg, J., Evans, C. D., Murdiyarso, D., Page, S., Renou-Wilson, F., Rieley, J., Sirin, A., Strack, M. & Tuittila, E.-S. (2016): *Greenhouse gas emission factors associated with rewetting of organic soils*. URL: https://doi.org/10.19189/MaP.2016.OMB.222

Wilson, J. B., Peet, R. K., Dengler, J. & Pärtel, M. (2012): Plant species richness: The world records. *Journal of Vegetation Science*, *23*(4), 796–802. URL: https://doi.org/10.1111/j.1654-1103.2012.01400.x

Windisch, W. (2021): Can we do without livestock? *Journal of Consumer Protection and Food Safety*, *16*(3), 193–194. URL: https://doi.org/10.1007/s00003-021-01338-w

Wittmayer, J. M., Hielscher, S., Fraaije, M., Avelino, F. & Rogge, K. (2022): A typology for unpacking the diversity of social innovation in energy transitions. *Energy Research & Social Science*, *88*. URL: https://doi.org/10.1016/j.erss.2022.102513

Witzke, H. P., Goetz, C., Kesting, M., Jansson, T., Dachbrodt-Saaydeh, S. & Strassmeyer, J. (2021): *Implementation of model adjustments for fertilizer restriction policies in the EU: Modelling policy restrictions on fertilizer and pesticide use in EU agriculture with CAPRI* (Deliverable D4). JRC, Joint Research Center. URL: https://publications.jrc.ec.europa.eu/repository/bitstream/JRC121368/pubsy_jrc_technical_report_-_capri_environmental_and_climatic_ambition_2.pdf

WRAP (Waste and Resources Action Programme) & WWF (World Wildlife Fund) (2020): *Halving food loss and waste in the EU by 2030: The major steps needed to accelerate progress*. URL: https://wrap.org.uk/resources/report/halving-food-loss-and-waste-eu-2030-major-steps-needed-accelerate-progress

Wróbel, B., Zielewicz, W. & Staniak, M. (2023): Challenges of pasture feeding systems: Opportunities and constraints. *Agriculture*, *13*(5), 974. URL: https://doi.org/10.3390/agriculture13050974

WWF (World Wildlife Fund) (2023): *The Forest Pathways Report*. URL: https://www.worldwildlife.org/publications/forest-pathways-report-2023

WWF UK (World Wildlife Fund) (2021): *Driven to Waste: The Global Impact of Food Loss and Waste on Farms*. URL: https://wwfint.awsassets.panda.org/downloads/technical_report___wwf_farm_stage_food_loss_and_waste.pdf

Zehlius-Eckert, W., Tsonkova, P. & Böhm, C. (2020): *Umweltleistungen von Agroforstsystemen*. URL: https://agroforst-info.de/wp-content/uploads/2021/03/02__Umweltleistungen.pdf

Ziegler, R., Wichtmann, W., Abel, S., Kemp, R., Simard, M. & Joosten, H. (2021): Wet peatland utilisation for climate protection: An international survey of paludiculture innovation. *Cleaner Engineering and Technology*, *5*. URL: https://doi.org/10.1016/j.clet.2021.100305

Zöllmer, J. & Grethe, H. (2024): Enabling free movement but restricting domestic policy space? The price of mutual recognition. *European Policy Analysis*. URL: https://doi.org/10.1002/epa2.1208

ZukunftMoor GmbH (2024): *Torfmooskultivierung als möglicher Transformationspfad für Paludikultur auf Hochmoorstandorten. Hintergrundpapier*. Unpublished.

Publication details

About Agora Agriculture
Agora Agriculture develops science-based and politically feasible approaches for a sustainable food, agriculture and forestry sector. As part of the Agora Think Tanks, the organisation works independently of economic and partisan interests and aims to contribute to achieving democratically negotiated sustainability goals such as climate neutrality and biodiversity protection.

Agora Agriculture
Agora Think Tanks gGmbH
Anna-Louisa-Karsch-Straße 2
10178 Berlin | Germany
P +49 (0) 30 7001435-000

www.agora-agriculture.org
info@agora-agrar.de

Proofreading: Paul Mundy, Karen Matzke
Typesetting: Theo Becker | Elser Druck GmbH
Title picture: Adam Smigielski | iStock

336/08-S-2024/EN
Version 2.2, May 2025

This publication is available for download under this scan code.