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Drivers of food security

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1. Introduction

Today food security is at the forefront of the political agenda, both at the EU and global levels. Ensuring the availability and access to food for consumers at reasonable prices are objectives set out in Article 39 of the Treaty on the Functioning of the European Union (TFEU). However, the achievement of these objectives cannot be taken for granted.

Food security sits at the nexus of society, agricultural production, climate, biodiversity, energy, health, technology, peace and security. Without farmers and fishers, there is no food on our table. As such, ensuring a fair standard of living for these communities is of paramount importance for food production. With high pressure on the global food system, and as food production is predominantly based on natural processes and yields are inherently uncertain, vulnerabilities become more relevant in times like the ones we are currently living in.

Over the years, the Common Agricultural Policy (CAP) has played an important role in making EU agriculture one of the world's leading food producers, which in turn guarantees the food security for 450 million European citizens and contributes to global food security. European farmers are responding to citizens' demands regarding food supply, safety, quality, and sustainability.European farmers are responding to citizens' demands regarding food security, safety, quality, and sustainability.In fisheries and aquaculture, the Common Fisheries Policy (CFP) aims to ensure that fishing and aquaculture activities are sustainable and contribute to provide Europeans with nutritional food.

At the heart of the European Green Deal, including the Farm to Fork, the Biodiversity and other strategies, the EU set out a long-term strategic vision on how to change the way we produce, distribute, and consume food. This vision aims at fair, healthy and environmentally-friendly food systems, while further strengthening their overall resilience.

In recent years, the effects of climate change and environmental degradation have put food systems, including agricultural, fisheries and aquaculture production, under increasing pressure all over the world. Food systems belong among the major drivers of climate change and biodiversity loss, and the same time, food production is among the most affected by them. In addition, food systems can provide a wealth of solutions to these challeneges.

Against the backdrop of the global economic disruptions stemming from the COVID-19 pandemic and the Russian invasion of Ukraine, trade flows have been interrupted, and this has negative implications for the supply of key agricultural commodities and inputs. This has further destabilised global food systems and intensified food insecurity risks and vulnerabilities across the world.

This staff working document aims at analysing the main drivers affecting food security from both the supply and demand sides ([1]). Relying on an evidence-based approach, this document provides a factual assessment of the key drivers and their interlinkages, to inform the ongoing debate in today's context. It looks at short and longer term horizons and linkages between the drivers. Stakeholder views, collected through specific consultations, have been taken into account in the analysis.

([1]) This document does not replace any impact assessment associated to any specific legislative proposal.

The European Commission's Communication of 23 March 2022 on 'Safeguarding food security and reinforcing the resilience of food systems' put forward a number of short- and medium-term measures to safeguard global food security, while supporting EU farmers, fishers, and consumers most affected by Russia's invasion of Ukraine. Among other things, measures include support for a food security strategy for Ukraine, and for regions and population groups most affected by food insecurity; a support package of EUR 500 million, encompassing the mobilisation of the crisis reserve; an amended Temporary Crisis Framework for State aid; an exceptional temporary derogation to allow the production of crops for food and feed purposes on fallow land; the possibility for Member States to reduce VAT rates and encourage economic operators to contain retail prices.

The EU, together with its Member States and the European Development Finance Institutions, is responding to short-, medium-, and longer-term food security challenges through a Team Europe approach along four strands of action: (i) a solidarity strand to step up emergency aid and macro-economic support; (ii) a sustainable production strand to strengthen local food production systems and resilience; (iii) a trade strand to keep markets open and get grains out of Ukraine, especially via Solidarity Lanes and support to the UN and Turkey-led Black Sea Grain Initiative; and (iv) a multilateral strand to work closely with international partners, notably the UN. The Solidarity Lanes intitiative together with the Black Sea Gran initiative has enabled the export of above 30 Mt of cereals, oilseeds and related products from Ukraine between May and November 2022.

The EU has launched many initiatives to safeguard food security, strengthen the resilience of food systems, and to guarantee the availability of supplies ([2]). This brings tangible progress in achieving the UN Sustainable Development Goal 'Zero hunger' (SDG2), which focuses on ending hunger and malnutrition, increasing sustainable agricultural production, and reducing its environmental impacts among other things. Moreover, the EU is committed to achieving SDG14, as well as conserving and sustainably using the oceans, seas, and marine resources by implementing the Common Fisheries Policy.

2. Conceptual framework for the analysis of drivers of food security

At the World Food Summit in 1996, food security was defined as 'when all people, at all times, have physical and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life'([3]). This widely accepted definition points to four dimensions of food security:

- **Food availability** refers to the availability of sufficient quantities of food of appropriate quality, supplied through domestic production, imports or food aid.

([2]) Commission Communication, 'Contingency plan for ensuring food supply and food security in times of crisis', COM(2021) 689 final; Commission Communication, 'Safeguarding food security and reinforcing the resilience of food systems', COM(2022) 133 final; Commission Communication, 'Temporary Crisis Framework for State Aid measures to support the economy following the aggression against Ukraine by Russia', COM(2022) 7945 final; Commission Communication, 'Ensuring availability and affordability of fertilisers', COM(2022) 590 final.

([3]) FAO, Trade reforms and food security, Conceptualizing the Linkages, 2003, Chapter 2. Food security: concepts and measurement.

- **Food access** refers to individuals having adequate resources to acquire appropriate foods for a nutritious diet.
- **Utilisation** relates to an individual's nutritional well-being reached through adequate diet, clean water, sanitation, and healthcare.
- **Stability** is the condition by which the dimensions of availability, access and utilisation are sufficiently met, and in which the whole system is stable, thus ensuring that households are food secure at all times. Short-term instability can lead to acute food insecurity, and medium- to long-term instability can lead to chronic food insecurity. Climatic, environmental, economic, social, and political factors can all be a source of instability.

Recently ([4]), the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security highlighted two additional dimensions. The first one is the importance of agency, which is the capacity of the food system's actors to make their own decisions about food. The second is sustainability, which is the long-term ability of food systems to provide food security in a way that does not compromise the economic, social, and environmental bases that generate food security for future generations.

Sustainability is considered in this widely accepted definition of food security. The mention of 'at all times' implies not only short-term instabilities in food systems, but also the long-term dimension. Short- and long-term drivers of food security and its intermediary outcomes, are highly interlinked. While long-term drivers determine trends, short-term shocks are part of this trend and often bear long-term consequences. Long-term drivers can themselves cause short term shocks – the droughts in 2022 are a sad example. Policy responses to short-term shocks must consider long-term consequences and goals.

Food availability is not at risk in the EU today. The EU is largely self-sufficient for key agricultural products and achieves a stable overall food export surplus. It is a main wheat and barley exporter, and largely able to cover its own consumption needs for other staple crops, such as maize and sugar. The EU is also largely self-sufficient for animal products, including dairy and meat, with the notable exception of seafood.

However, the current food price inflation, estimated at 18% in October 2022 ([5]), endangers food affordability for the most vulnerable households. As a result, households spend a larger share of their budgets on food, potentially compromising the diet quality if they switched to products that contain more calories while being poorer in micronutrients. While the most severe forms of hunger, including undernourishment, are rare in the EU, self-reported moderate or severe food insecurity in the EU increased between 2019 and 2020. The growing food price inflation has made the situation worse, and aggravates the increased pressure on households' incomes, alongside energy costs, fuel costs, etc.

([4]) HLPE. 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, Rome.

([5]) Eurostat HICP - monthly data (annual rate of change)

Globally, acute food insecurity is increasing ([6]) and affected up to 222 million people in 53 countries/territories in mid-2022. The situation is likely to deteriorate further in many countries and 'hunger hotspots' ([7]). Soaring food prices are especially affecting the poorest households in developing countries as they often spend more than 50% of their income on food. An estimated 3.1 billion people (42% of the world population) could not afford a healthy diet in 2020 ([8]). Food insecurity increases humanitarian needs and fuels social unrest, instability, and conflict, and vice versa. It can also weaken the respect of human rights and exacerbate gender inequality.

Figure 1 illustrates the conceptual framework used for this analysis of the drivers of food security within the EU. It builds upon previous work, in particular the High Level Panel of Experts' ([9]) conceptual framework of food systems for diets and nutrition.

As formulated by the FAO ([10]), a sustainable food system delivers food security and nutrition for all in such a way that the economic, social, and environmental bases to generate food security and nutrition for future generations are not compromised. A sustainable food system should thus ensure and contribute to all elements of environmental, social, and economic sustainability. There are seven main categories of drivers that affect the ability of food systems to deliver healthy and sustainable diets for all, while encompassing all the elements (environment, people, inputs, processes, infrastructures, institutions, etc.) and activities that relate to the production, processing, distribution, preparation and consumption of food, and the outputs. These are ***biophysical*** and ***environmental*** drivers; ***research and innovation, and technology****;* ***economic*** and ***market drivers***; ***food value chain performance***; ***political*** and ***institutional*** drivers; ***socio-cultural*** drivers, and ***demographic*** drivers. This analysis focusses on the drivers that are especially relevant for ensuring the EU's food security today and tomorrow.

The drivers (mainly) affect the food security at different levels and with a different magnitude. Some shape *macro*-level conditions in which our food systems exist. Other drivers affect the *food supply chain*, i.e. food production systems as well as all other activities that move food from production to consumption, while some others directly affect *individuals and households* and shape the way in which consumers acquire, prepare and consume food.

The drivers and underlying trends, such as extreme weather patterns, biodiversity loss, higher input costs - just to name a few - are profoundly interconnected and interact with each other in multifaceted ways across the food system.

([6]) Global Report on Food Crisis 2022, Mid-year Update

([7]) Hunger Hotspots (September 2022), FAO-WFP

([8]) The State of Food Security and Nutrition in the World report (2022)

([9]) 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. September 2017. HLPE Report 12. Food security and nutrition: building a global narrative towards 2030 (fao.org)

([10]) https://research-and-innovation.ec.europa.eu/strategy/support-policy-making/scientific-support-eu-policies/group-chief-scientific-advisors/towards-sustainable-food-system_en

https://www.fao.org/3/ca2079en/CA2079EN.pdf

A concept that recognises the complex interlinkages between many of the drivers of food security described in this analysis is the 'One Health approach' that 'is an integrated, unifying approach that aims to sustainably balance and optimise the health of humans, animals, plants, and ecosystems. It recognises that the health of humans, domestic and wild animals, plants and the wider environment (including ecosystems) are closely linked and interdependent.

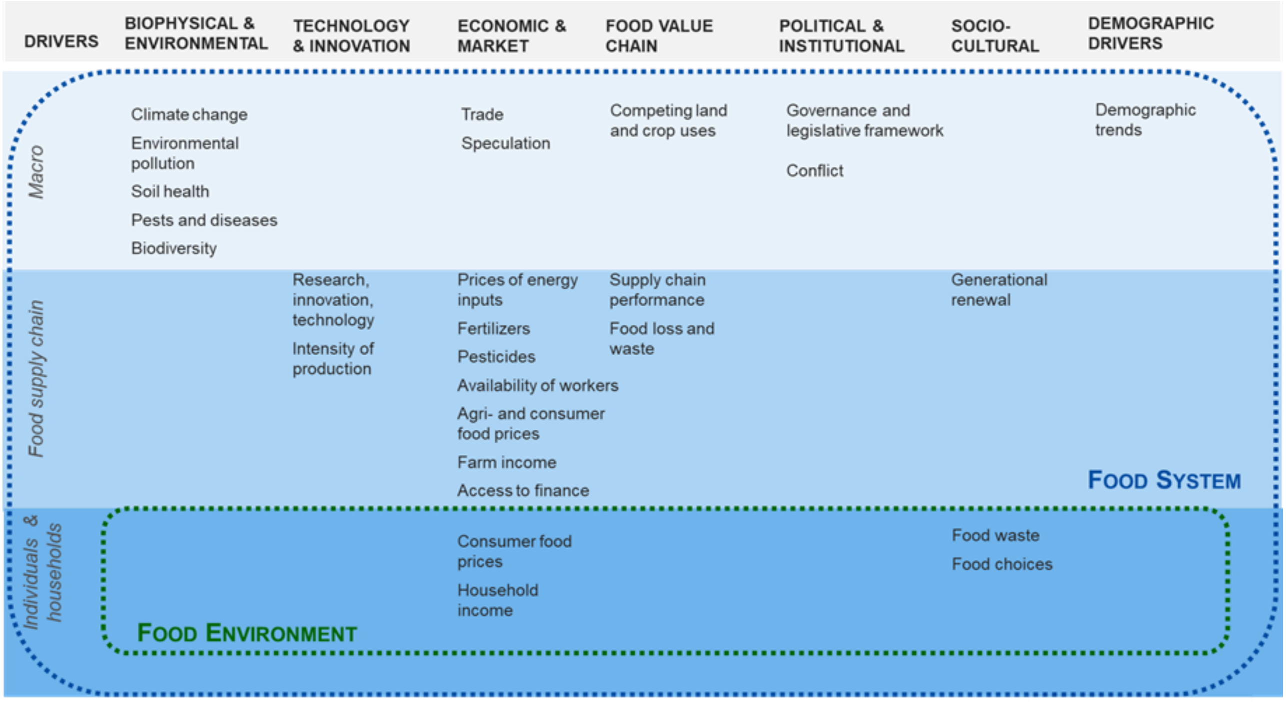

Figure 1: Conceptual framework for the analysis of drivers affecting food security in the EU as discussed in the Staff Working Document.

3. Overview of the main elements of the drivers identified

3.1. Biophysical and environmental drivers

Soil, water, biodiversity, and air are basic requirements for food production. Biophysical and environmental drivers leave a major imprint on the land as EU´s major resource for food production, inducing land cover and land-use changes and thus affecting food production systems. This analysis has identified that the current high input intensive agricultural model, based on chemical pesticides, is likely to pose a food security threat in the medium term due to a loss of biodiversity, the likely increase in pests, decline in soil health and loss of pollinators which are essential to agricultural production.

Different land uses compete in the EU: housing, infrastructure, energy generation, tourism and recreation, agriculture, etc. All of which have implications in terms of area available for agricultural production. Promoting a mixture of systems allowing for sustainable soil management, agriculture use and other uses in parallel, can help alleviate the tension. Agricultural land is allocated across different uses and objectives including animal rearing or the production of different crops for food, animal feed, bio-based products or biofuels.

In 2020, according to the last Eurostat Integrated Farm Statistics (IFS) census, 61% of agricultural land is used as arable land, 31% is covered by permanent grassland, while the rest is used for permanent crops. In the last marketing year, more than half (56%) of the surface devoted to arable land was used for feed, while 28% is used for food and 7% for biofuels (these shares depend on crop choices, product quality and market demand).

Enhancing the resilience of primary production systems to sustain food security requires a multi-dimensional and interacting approach. This includes action aimed at reducing pollution and chemical inputs, closing nutrient cycles, fostering biodiversity, sustainable use of fresh and marine waters and soil health, reversing pollinator decline, as well as better protection against climate change while maintaining vital ecosystem services. The Intergovernmental Panel on Climate Change (2022) notes that "options that promote intensification of production have been widely adopted in agriculture for climate change adaptation, but with potential negative effects. Integrated and systems-oriented solutions to alleviate competition and trade-offs between mitigation and adaptation will reinforce long-term resilience and equity in water and food systems" ([11]).

Primary production and the whole food supply chain are highly vulnerable to the impacts of ***climate change** and **biodiversity loss***. Changes in weather patterns induced by climate change are already jeopardising food production in Europe, and the impacts will worsen in the coming years. The consequences for regional agriculture production and food habits will be significant. Furthermore, the largest socio-economic and food security impacts will occur in regions where the natural resources needed for production are under particular stress.

For marine fisheries, the overall exploitation rate decreased, while biomass of stocks increased, in the North-East Atlantic over the period 2003-2020. Still, many stocks are overfished and/or outside safe biological limits or still lack full scientific assessment (STECF, 2022). The situation regarding stocks in the Mediterranean and Black Seas remains challenging with annual exploitation rates twice the optimal ones over the period 2003-2019. Improvements to fish stocks should result in slight increases in future fishing opportunities, which would improve the resilience of the EU fishing fleet. Yet, adverse effects from climate change will increasingly affect fish stocks, while key stressors, such as human impacts on marine biodiversity, pollution, and invasive alien species, should be addressed as a matter of urgency to help comprehensively address the crisis and help sustain fish stocks.

Around one third of the EU area suffers from water stress and warming. This is especially the case in Southern Europe and the Mediterranean region, which is seriously threatened by desertification. In the absence of ambitious and effective global mitigation actions, models forecast a further 2-5°C temperature rise in Europe over the next decades, resulting in a northward shift of current climatic zones (Masson-Delmotte et al., 2022). Extreme climatic events, such as severe droughts and heatwaves occur with increasing frequency (Vogel, 2020; Toreti, 2019; Seneviratne, 2021). This generates an actual risk that concurring and combined hazards from climate change (such as invasive alien species, pest outbreaks, and emerging diseases, increased severity of wind and hailstorms) might already hit some of the world's key agricultural production and trigger international market shocks, higher volatility, and price spikes within the next few years. Implementing targeted local adaptation strategies, such as switching to less water demanding crops, improving soil health and its sponge capacity, modernising existing irrigation systems by implementing water saving irrigation techniques, deploying integrated nutrient management plans, improving long term planning, and leveraging

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([11]) IPCC_AR6_WGII_FullReport.pdf

international trade may alleviate some of the climate change impacts. Maladaptation, which can undermine longer-term resilience or the resilience of other users, has been observed across many regions, but should be avoided. E.g. the use of high-cost irrigation in areas that are projected to have more intense drought conditions, or the planting of unsuitable tree species ([12]).

Environmental pollution, i.e. degradation of natural resources (air, water, soil), negatively affects food security. Evidence shows that ozone air pollution reduces EU staple crop yields by 5-10% (Van Dingenen, 2009; Mils, 2018), and that such a reduction might be cut by half if substantial air pollution reduction measures are implemented. Although it poses a serious health hazard, air pollution from airborne particulate matter has moderate, and multi-directional effects on crop production. Globally food-systems are responsible for about a third of particulate matter emissions.

Agriculture is also the main source of nitrogen discharge into watersheds. In many EU countries the use of animal manure and synthetic fertilisers causes high levels of nitrate in surface waters and groundwater. In addition to pollution from emissions and by-products of human activities, potentially harmful substances are often released in the environment, either intentionally to combat pests (e.g. pesticides) or collaterally as part of waste management practices (e.g. landfills). However, some properly treated organic waste streams enrich the soil with nutrients and organic matter (e.g. manure, sewage sludge, compost, digestate from anaerobic digestion). Chemical pollutants (e.g. pesticides, nutrients, heavy metals, plastics and microplastics) can have multiple negative effects on both terrestrial and aquatic (freshwater and marine) ecosystems, compromise the quality of drinking and irrigation water, degrade the quality of soil and of seafood, and have direct impacts on human health. Eutrophication in marine and freshwater ecosystems can have broad effects on the natural interconnection of food chains, affecting fisheries by reducing the production at higher trophic levels (e.g., fish, shellfish, etc.). Human activities at sea also contribute to environmental pollution. Aquaculture practices may discharge nutrients, veterinary products and organic matter that can lead to pollution if not appropriately managed. Macro- and microplastic is also released into the marine environment through lost or discarded fishing gears and the wear of aquaculture facilities.

In the EU, 95% of food is produced on land and depends on ***soil health***. Intensive agriculture with high chemical inputs together with unsustainable drainage increased potential for soil erosion. The spread of persistent pollutants are the main drivers of soil degradation. Through filtering and transformation, soil can accumulate pollutants and become a potential source of pollution for air and water, as well as the food chain.

Moreover, urbanisation and infrastructure construction often leads to an irreversible loss of fertile soils. Unhealthy soils are less fertile and less resilient to erosion and extreme weather events, increasing the damages resulting from flooding, droughts and landslides, and losing its ability to store carbon ([13]). In many cases, it may take decades or centuries for the soil to recover. Currently, about 65-75% of EU's agricultural soils are losing organic carbon due to an

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([12]) IPCC_AR6_WGII_FullReport.pdf

([13]) Byrne, K.A., Lanigan, G., Creamer, R., Renou-Wilson, F. (2018). Soils and Carbon Storage. In: Creamer, R., O'Sullivan, L. (eds) The Soils of Ireland. World Soils Book Series. Springer, Cham. https://doi.org/10.1007/978-3-319-71189-8_17

Lal, R. (2016). Soil health and carbon management. Food and Energy Security 2016; 5(3): 212– 222 https://doi.org/10.1002/fes3.96

excess of nutrients and/or eroding (or compacting) and/or suffering secondary salinization (Veerman et al., 2020). The costs associated with soil degradation ([14]) are estimated at around EUR 15 billion per year. 12 million hectares of agricultural area in the EU affected by severe erosion are estimated to lose around 0.43% of their crop productivity annually (annual cost of EUR 1.25 billion) (Panagos et al., 2018).

Pests and diseases negatively impacts food production and food availability. Globally, up to 40% of food crops are lost due to plant pests and diseases (Savary et al 2019; Renault et al 2022). Scientific evidence shows that pests move and invasive alien species spread into new habitats due to rising temperatures. Agricultural systems defined by monocultural production also increase the prevalence of pests and pest damage. In the EU, the cumulative impact of only some regulated quarantine pests, which are still absent from the Union territory or present with limited distribution, could exceed EUR 25 billion of losses yearly, representing around 20% of the total EU production value. These pests would put a total value of EUR 22 billion of agricultural exports at risk. This would also mean -3.2% of current calories supply, -2.2% of protein supply, and -1.0% of fat supply (Sanchez et al., 2019). Globalisation, human mobility and international trade increasingly expose crops and animals to alien/emerging pathogens and invasive pests. Over 11,000 invasive species have already spread into Europe at an increasingly higher rate (Hulme et al. 2009). These species already cost taxpayers EUR 12.5 billion annually ([15]). Global yield losses due to insect pests for wheat, rice and maize are projected to increase by 10-25% for each degree of global mean surface warming.

Animal diseases can severely affect livestock and aquaculture sectors and lead to potential production losses. Measures that must be taken to control disease outbreaks can lead to restrictions on the use of animals and products from these animals. While food security in the EU is not endangered by animal diseases, they can also negatively affect the EU as underlined by the recent animal health crises.

Land is also an integral part of ecosystems and an indispensable factor for ***biodiversity*** and ecosystem services. Ecosystem services range from biomass provision (e.g. crop, fibre, timber and fisheries) filtration of pollutants (from air, water and soil) to the protection from natural hazards (e.g. flooding and landslides) and maintenance of habitats (e.g. pollination, pest control and carbon sequestration). Genetic diversity improves the resilience to climate change, pests, and diseases.

Ecosystem services and natural capital are vital for economic output, in particular in the agricultural sector. For instance, 1.3 million of the 9.6 million farming jobs in the EU are linked directly or indirectly to Natura 2000 ([16]). Agricultural habitats largely shaped by farming are essential to wildlife, and healthy biodiversity and functioning ecosystems make food systems, livelihoods and the society at large more resilient to shocks and stress, e.g. from climate change (Dainese et al., 2019).

In the EU, ecosystem contribution to crop provision is about 21% of the total yield value. The rest is due to human inputs (i.e. planting, irrigation, labour, and chemical inputs). Accordingly,

([14]) Water erosion, loss of phosphorus, loss of carbon due to soil erosion, land use change, sediments removal and management of contaminated sites.

([15]) Considering that for almost 90% of invasive species information on impact in Europe is missing, this arguably represents a rather conservative estimate (Vila et al. 2010)

([16]) https://www.eea.europa.eu/soer/2015/europe/natural-capital-and-ecosystem-services landscapes and habitats that facilitate biodiversity benefit the overall stability of crop production. The creation and preservation of highly diverse landscape types and features on agricultural areas is thus important to restoring biodiversity and improving agricultural productivity in the long run. A prominent example is insect-based pollination, which provides vital ecosystem services to crops and wild plants. Currently, at the European level, about 50% of the pollinator dependent crops face pollination deficits. Collectively, pollinators contribute more than EUR 14 billion per year to the market value of European crops ([17]).

The decreasing diversity of pollinators, insectivores, and other beneficial organisms is likely to reduce yields and make crops more vulnerable to pests, pathogens, and invasive alien species in the long term. In turn, recurring outbreaks of pests and pathogens will bring about more use of pesticides and antibiotics, with likely harmful effects on wildlife, habitats and humans. Equally, the reduction of high diversity landscape features (fallow, ponds, inter-field strips, hedges, trees) increases the exposure of crops and livestock to heatwaves, frost, floods, pest outbreak, soil erosion, water depletion in soil. Fallow land on field corners and marginal areas does not usually lower yields, but may increase them on the medium and short term ([18]). Protected areas, including Natura 2000 sites, are key for biodiversity and for sustaining agricultural production, especially for quality products.

3.2. Research, innovation and technology

The latest OECD-FAO Agricultural Outlook projections (2022-2031) suggest that to achieve the Zero Hunger target while simultaneously keeping agricultural emissions on track to reach the Paris Agreement targets, average global agricultural productivity would need to increase by 28% in a sustainable way over the next decade. This is more than triple the increase recorded in the last decade.

Investments in research and innovation, technological development, knowledge transfer, and reskilling act as enabling factors to achieving higher efficiency food production while minimising the effects on the natural resources. Access to knowledge and new technologies is needed to increase productivity, reduce inputs, develop alternatives, and reduce pre- and post-harvest losses. It also helps find novel value chains for inevitable food losses at post-harvest management systems ([19]), improve energy efficiency, foster sustainable use of water resources, promote the use of bio-based products, enhance food safety, and improve resilience to climate-related and other shocks, while preserving biodiversity. This contributes to the availability and stability of the food supply (e.g. Fuglie, 2018). In addition, it can explore alternatives to on-land farming by supporting sustainable fisheries as well as sustainable and resilient aquaculture systems, including the use of low trophic species (e.g. algae), high animal welfare standards and alternative sources of protein for food and feed.

In addition to public and private investments, a suitable regulatory framework is necessary to facilitate and steer innovation towards technologies and agricultural practices that would have the greatest effects on food security. Precision agricultural technologies (sensors, ICT, robotics and data-driven decision support systems) and New Genomic Techniques (NGTs) are identified as technologies with a potential to contribute to sustainable and resilient food systems, and thus

([17]) https://ipbes.net/assessment-reports/pollinators

([18]) Pywell et al. 2015; https://doi.org/10.1098/rspb.2015.1740

([19]) Horizon 2020 projects: Succelog, AgroLink, UPrunning food security in the EU. At the same time, investments in dissemination, diffusion of knowledge, and improvements to education and training also plays a crucial role in ensuring the uptake of new production technologies and approaches.

3.3. Economic and market drivers

Trade allows for the movement of food commodities from surplus producers to deficit countries. By contributing to food availability and access, thus lowering prices, trade is considered to have an overall positive impact on global food security (Fader et al. 2013; Porkka 2013, 2017), as well as on nutrition and health (Hawkes et al., 2015). In a global context, the EU is a significant producer and the main net exporter of agricultural goods. The EU Single Market is a cornerstone of EU food security as it enables a diversity of supplies coming from different climate and geological zones in the EU.

Although oriented towards the export of high value elaborated food products, the EU also plays a major role in supplying primary and first processed food products to import-dependent, in particular developing countries, in particular cereals (wheat) and animal products (dairy and meat). At the same time, the EU is also one of the major importers of food products, both of final goods, such as tropical goods, fishery and aquaculture products, and agricultural intermediate inputs, such as vegetable proteins (soya) and cereals (maize), used mainly as feed for its livestock production.

The invasion of Ukraine by Russia disrupted trade flows of key agricultural commodities and increased the pressure on international food supply chains, already under stress even before the war. Negative effects on trade were further exacerbated by trade-restrictive policy measures adopted by some countries (e.g. India, Argentina, Serbia, etc.), including: export bans or taxes on key agricultural commodities (e.g., cereals, oilseeds and oils), inputs for the food processing sector (e.g., whitefish), and on key inputs necessary for food production (e.g., energy, fertilisers).

Financial speculation in food commodity markets contributes to their correct functioning by increasing market liquidity and bearing some of the risk. However, if speculation becomes excessive, driven more by financial market strategies than by food market fundamentals, it may distort price dynamics, for example by enhancing already existing price developments. No increase in direct financial speculation has been identified when the price of agricultural commodities increased during 2022 ([20]).

The impacts on the environment in the form of environmental externalities are often not reflected in market prices. This can distort behaviour and, in turn, cause a yields decline over time. Subsidies that support unsustainable production may sometimes worsen the situation.

The entire food chain needs reliable ***energy*** supplies. Interruptions to the energy supply as well as increasing energy prices negatively affect the food chain at various stages. Energy prices have considerably risen during the last two years, with the invasion of Ukraine by Russia amplifying the increase, particularly natural gas. After increasing from around EUR 40 per

([20]) In the energy market, in its latest Financial Stability Review, the ECB looked at extreme price dynamics and did not even mention speculation. There is no evidence that excessive speculation drove energy prices: https://www.ecb.europa.eu/pub/financial-stability/fsr/special/html/ecb.fsrart202211_01~173476301a.en.html barrel in 2020 to reaching a peak in March and June 2022 of EUR 120/barrel, the Brent crude oil price decreased to about EUR 90 in October 2022. The price of coal and gas also spiked and in August 2022 was more than four times higher than the 2020 average. In comparison to other areas in the world, gas price increases are even higher in Europe, with this having significant impacts on the price of electricity. Although the share of energy inputs in the production of agricultural, fishery, and aquaculture commodities can vary across regions, higher energy prices inevitably imply higher production costs. As **energy represents a considerable share of the production costs** for the farming and fishery sectors, higher energy prices can lead to lower input use and, therefore, to lower output and higher commodity prices. While increased commodity prices impact consumer food prices, retail prices are generally also impacted by higher energy costs in the food processing, distribution and marketing stages.

Mineral ***fertilisers*** play a significant role for food security. **Fertiliser prices are directly connected to energy prices**, the production of nitrogen fertilisers being especially highly energy intensive. A large amount of mineral fertiliser is traded on international markets, but only sourced by a few countries, among them Russia and Belarus. The EU is largely dependent on imports of mineral fertilisers, and high import dependency and high energy costs put the fertiliser supply under pressure, negatively affecting agricultural productivity in many parts of the EU and globally. More efficient use of fertilisers on farms (e.g. with enhanced nutrient management plans, soil conservation programs, precision agriculture, enhanced rotation of crops with more leguminous plants) and closing of nutrient cycles, in line with the Farm to Fork target to significantly reduce nutrient losses, can help to mitigate pressure from increased fertiliser prices, while contributing to stable yields.

Crop protection is crucial to minimising pre-harvest losses due to pests and diseases, and thus to safeguard food security. Pesticides (i.e., fungicides, herbicides, and insecticides) are used for this purpose. Some EU Member States have among the highest pesticides use in the world ([21]). The current higher transport and energy costs may result in a modest rise in pesticides prices, but this is not expected to lead to a large cut in pesticide use in the EU. Pesticides have proven to be effective in preventing possible shortfalls in obtainable yields and ensuring yield stability. However, the (mis)use of pesticides has numerous unintended environmental consequences that could adversely affect food security in the medium- to long-term. Adverse effects of pesticides on pollinators, for example, threaten crucial ecosystem services (Gallai et al. 2009; Losey and Vaughan 2006). In addition, some pesticides are cumulating in the environment and entering the food chain. It is therefore increasingly acknowledged that sustainable crop protection must integrate alternative and lower risk plant protection products, as well as agronomic and technological strategies, as formulated in the Integrated Pest Management (IPM) principles. Novel technologies, such as precision agriculture and New Genomic Techniques (NGT), as well as advances in IPM practices, organic farming, agro-ecology and nature-based farming practices are expected to support the transition towards a lower pesticides' dependency.

The ***availability of workers*** along the food value chain has a direct impact on the capacity of the sector to supply the EU market with food. Some EU regions are short of seasonal workers, which can lead to lower a harvest and output quality. In addition, the EU faces a more structural problem concerning a shortage of skilled labour in agriculture. The depopulation of rural areas, working conditions, lower attractiveness compared to other sectors, and specific training needs

([21]) FAOSTAT (2022). https://www.fao.org/faostat/en/#data/RP are the main factors behind the shortage of skilled agricultural labour. Furthermore, a large share of workers is of foreign origin and their availability depends on the conditions of migrants in the different Member States. Migrant workers can exert a positive impact on agricultural sector competitiveness and represent a solution for the structural shortages of labour in the farm sector (European Parliament 2021, Antonioli et al. 2022). There is also a particular concern for fishing crews as some vessels have been lying idle due to the steep increase of fuel prices. Since crews are paid through shared remuneration systems rather than a fixed wage, wages can significantly vary with the economic performance of the vessel. Consequently, crews may be progressively leaving the sector. Moreover, upskilling, reskilling, better education, and access to good quality of professional training for farmers, fishers and workers in the whole food supply chain remains fundamental to ensure a viable food production in the EU.

The allocation of the ***agricultural land use*** is shaped by policy incentives and demand for different products and services. Agricultural land is allocated across different uses and objectives including animal rearing or the production of different crops for food or industrial use, animal feed, or biofuels.

Agricultural land accounted for 39% of the EU land area in 2018 ([22]). Despite a reduction in the last decade, land take related to the expansion of built-up areas, mostly affected to the detriment of agricultural areas, amounted to 539 km^2/year in the EU between 2012 and 2018. Between, 2000 and 2018, an estimated 0.6% of total arable land was lost ([23]).

Agriculture is responsible for 10.3% of the **EU's GHG emissions** and nearly 70% of those come from the animal sector[24]. In Europe, around 65% of agricultural land is used for animal production (around 55 million ha of arable land and up to 51 million ha of permanent grassland, which cannot be readily cultivated and are used exclusively by ruminants)[25]. Maintenance of permanent grassland is important to increase soil carbon stocks and enhance biodiversity.

CROPS		
Utilised agricultural area	161.963,84	100%
Arable land	98.570,38	61%
Permanent grassland	50.642,28	31%
Permanent crops	12.256,41	8%

Eurostat (2020 Census)

Livestock is an essential source of food production, important for the economy and vitality for many regions. The impact of livestock production on the natural environment depends on the

([22]) https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Land_use_statistics&oldid=575412

([23]) https://www.eea.europa.eu/data-and-maps/indicators/land-take-3/assessment

[24] EEA (2019), *Annual European Union greenhouse gas inventory 1990-2017* and *Inventory report 2019*. These figures do not include CO_2 emissions from land use and land use change.

[25] Agricultural census 2020 - Agriculture - Eurostat (europa.eu).

farming system implemented and the territory in which it operates. Meat and dairy products lead the list of EU's agricultural exports, followed by wine. The sustainability of livestock can be improved through a number of measures to reduce physical flows, such as nutrients, greenhouse gases, and toxic substances, substitution of high impact inputs with lower impact alternatives, and enhancement of circular approaches, e.g. use of manure for the production of bio-fertilisers ([26]).

In the EU, about 55% of cereals are used for feed and about 4% for the production of biofuels (bioethanol). The increase in bio-based products and the general development of the bioeconomy is expected to be achieved without additional pressure on the use of land for food, provided that the raw materials will not be produced on land that could be used for food crops, especially when considering the concept of a circular economy. Land use for carbon farming practices increase organic matter in soils, thus enhancing soil fertility, thus positively affecting food security. However, change of land uses for carbon sequestration requires monitoring and coordination in order to avoid possible adverse effects on food security.

Heightened ***prices for inputs***, such as fertilisers and fossil energy, can cause production challenges. This may affect supply certainties and thus food availability. On the other hand, increasing farm-gate or landing prices may actually raise the returns to producers and boost food production and food availability. While already high in the wake of supply disruptions related to transport and logistics bottlenecks and the surge in global demand during the recovery from the COVID-19 pandemic, Russia's war against Ukraine provoked a further surge in food commodity prices. The FAO's international food price index climbed to its all-time high in mid-May 2022. Some agricultural commodity prices have since returned to pre-war levels but remain high ([27]).

The interplay between the input costs and farm-gate prices for food crops determines ***farm income***. Farm income in the EU is also increasingly determined by other factors, such as renewable energy production (biogas, wind, solar), tourism services (hosting, restoration), as well as the severity and frequency of natural hazards etc. Farm income determines the short- and long-run supply response of farmers. For the fishery sector, the economic performance and viability of the sector remains very dependent on the fuel prices. Lower incomes will translate into reduced capacity to use inputs in the short-term and to invest in the long-term. This can lead to lower and more variable yields and overall lower production, thus affecting the stability and availability of food. Farmers may also change their activities (crop allocation) in response to market signals and expected returns. The impact of such changes on food security is unclear. The structure of farm income varies largely, depending on the type of farm, i.e. size and the level of specialisation of production. In the long run, a general reduction of farm income will influence farm viability, with an increased risk of farms halting their activities. The increase in agricultural prices may contribute to compensate for farmers' higher input costs, in particular in the arable crop sector so far in 2021 and 2022, and for farmers who sell on future markets or

([26]) European Commission, Directorate-General for Agriculture and Rural Development, Peyraud, J., MacLeod, M., Future of EU livestock : How to contribute to a sustainable agricultural sector ? : final report, Publications Office, 2020, https://data.europa.eu/doi/10.2762/3440

([27]) http://www.amis-outlook.org/index.php?id=40373 can store and therefore postpone selling part of their production. However, for the livestock sector, the combination of surging feed and energy prices is likely to decrease income. Novel business models ([28]), e.g. combining livestock farming with remunerative biogas production can help farmers face such challenges and improve their income.

Access to finance is considered a key requirement for a viable food sector. Especially as smaller producers often face more difficulties in accessing finance than small- and medium-sized enterprises from other economic sectors in the EU. Access to finance at EU level, especially bank loans, is regarded as critical for many producers for both investment finance and working capital, with important differences between Member States (ESIF; EIB 2020 ([29])). In addition to investments for improving the productivity and sustainability of production, climate change adaptation is expected to require further investments by producers. Accordingly, facilitating access to credit for farmers and fishers is key to invest in viable and sustainable production facilities and practices across the EU, which in turn has direct positive effects on food availability and accessibility.

Consumer food prices are a crucial driver of food security, as they determine the quantity and quality of food that households and individuals can acquire or access. In addition, food inflation can fuel overall inflation and decrease disposable income, thereby further deteriorating economic access to food. While commodity prices for some staple foods have fallen back to pre-war levels recently, consumer prices continue to rise. Average consumer food price inflation in the EU was estimated at 18% by October 2022, with most Member States experiencing double digit-inflation at multi-decade highs. The largest increases are seen for oils and fats (+33%) with prices initially driven upwards by the lack of supply of sunflower oil from Ukraine and propagated to other direct substitutes. However, important price increases are also seen for foods like bread and cereals (+19%) milk, cheese and eggs (+24%), and vegetables (+22%) (Eurostat, 2022).

When faced with higher consumer food prices, especially poor households, who spend a large share of their budget on food, may choose more calorie-dense but micronutrient-poor and less diverse foods. This can result in health-related issues, including obesity, (micro) nutrient deficiencies, and non-communicable and diet-related diseases.

In addition to food prices, household resources and ***household income*** determine economic access to food. The stability of access to food is also likely to be a function of household income as food price shocks and other shocks have greater adverse effects on households at the bottom of the income distribution (i.e. those that usually spend a large share of their income on food). In 2021, an estimated 74 million people in the EU were at risk of poverty with an income below 60% of the national median (Eurostat, 2022). It is worth noting that higher incomes do not guarantee healthy diets. On the contrary, at global level, consumption of several unhealthy foods appears to increase with income (Global Diet Quality Project, 2022). At the same time,

([28]) Examples can be BiogasDoneRight in Po valley, Italy, AgriChemWhey in Ireland, small scale biogas in Ireland and Finland.

([29]) https://www.eib.org/en/publications/investment-report-2020

https://www.fi-compass.eu/sites/default/files/publications/financial_needs_agriculture_agrifood_sectors_eu_summary.pdf within high-income countries such as EU Member States, those with limited means often consume cheaper, energy dense and nutrient-poor diets.

3.4. Food supply chain performance

Households' physical access to food largely depends on the supply chains capacity to bring food to the consumers. This capacity is determined by the interplay of many services, such as transport, logistics, the availability of packaging, as well as the food environment. The costs associated with these activities also directly influence consumer food prices and economic access to food. More generally, a ***well-performing food supply chain*** requires operation of logistics and production facilities, access to inputs and markets, well-designed and responsive regulatory environment and competitive markets. The food supply chain is internationally interconnected and disruptions have increasingly been of transboundary nature. The COVID-19 crisis and ensuing recovery were characterised by many food supply disruptions related to transport and logistics bottlenecks. A key bottleneck during the COVID-19 crisis was sea-bound transportation, mainly caused by the disruption of the shipping sector. In addition to a persisting shortage of truck drivers and other labour for transport in the EU, the major factor currently affecting the functioning of the food supply chain are disruptions caused by Russia's war against Ukraine.

Food loss and waste along the food supply chain reduces productivity and can affect food availability, but also entails unnecessary greenhouse gas emissions and excessive use of scarce resources. In addition, the loss of marketable food can reduce producers' income and increase consumers' expenses. However, reaching food security inevitably implies a certain level of food loss and waste as a result of maintaining buffers to ensure food stability, discarding unsafe foods, and the fact that higher-quality diets tend to include more highly perishable foods. While Europe has some of the world's lowest food loss and waste rates in the supply chain until retail ([30]), new practices and technologies can help further limiting food loss and waste. Finding use for inevitable food loss in circular bioeconomy, including bioenergy, could contribute to food prices stability and bring many benefits ([31]).

3.5. Political and institutional drivers

Governance systems interact with food systems and food security in complex and interactive ways ([32]). The key actors engaged in food governance include public actors, such as governments and intergovernmental organisations, civil society, such as non-governmental agencies and social movements, and private sector actors, such as businesses. Main instruments at hand are international initiatives, legally binding rules, soft regulation, economic instruments, education and information. Such instruments operate on different timeframes and should include both short- and long-term interventions to support food security. For instance, legislative proposals have an inherent longer development period and deliver impacts on a forward-looking timeline. Governance systems guided by sustainability objectives and the

([30]) https://www.fao.org/platform-food-loss-waste/flw-data/en

([31]) Dahiya, S., Kumar, A.N., Shanthi Sravan, J., Chatterjee, S., Sarkar, O., & Mohan, S.V. (2018). Food waste biorefinery: Sustainable strategy for circular bioeconomy. Bioresource technology, 248 Pt A, 2-12 .

([32]) Food security and nutrition: building a global narrative towards 2030 https://www.fao.org/right-to-food/resources/resources-detail/en/c/1295540/

principle of the right to food are most likely to be effective in ensuring all dimensions of food security ([33]).

Conflicts can disrupt food production and other supply chain activities. The resulting reductions in supply can in turn affect prices and economic access to food. More broadly, conflict is likely to reduce economic activities and investment leading to declining household incomes and potential further deteriorations of access to food. The displacement of people associated with conflict creates a particular vulnerability to food insecurity given the loss of livelihoods, productive assets, basic living, and health infrastructure. Russia's war of aggression against Ukraine has disrupted important supplies and provoked a surge in food, energy, and fertiliser prices.

As mentioned above, food security exists only when people can access safe food. As such, ensuring food safety is crucial for achieving food security. In recent years, food safety standards have increased rapidly. Yet, in part due to climate change and an intensification of production, new food safety risks will continue to emerge, including antibiotic resistance and food contamination. Food systems must therefore continue to transform to adapt ([34]).

3.6. Socio-cultural drivers

Socio-cultural factors can also affect availability and utilisation of food. Attitudes towards life in rural areas and farming, for example, play an important role in ***generational renewal*** in the food sector. The latest Eurostat census on EU agriculture (2020) shows that the number of farms in the EU declined by 25% the last 10 years and that the increase in the average size of the remaining farms continues. In that process of structural change, the food sector appears to be less likely to attract young people than other sectors and the population engaged in farming and fishing in the EU is ageing.

Today in the EU, only about one in five EU farm managers are under the age of 45 and the proportion of young farmers in the overall farming population is declining. Only 1% of EU farm managers are below 25 years old (Eurostat). Similarly, about 30% of workers in the EU fishing fleet were below 40 (STECF 2022a) and 43% of the EU aquaculture sector (STECF 2022b).

The lack of attractiveness of agriculture has been related to lifestyle-oriented reasons and income differentials with other professions (Coopmans et al. 2021). Generational renewal in farming and fishery is seen as crucial for the long-term resilience and sustainability of food production systems. Therefore, attracting young farmers and facilitating business development in rural areas is one of the key policy objectives under the EU's Common Agricultural Policy 2023-2027.

Food waste through consumption is the hotspot for food waste in the EU. In 2020, EU consumption in households and in food services were estimated to have wasted 82 kg of food per inhabitant, accounting for 64% of the estimated 57 million tonnes of fresh mass wasted. It is roughly estimated that around 10% of food made available to EU consumers (at retail, food

([33]) FAO, SOFI report 2022.

([34]) FAO and WHO: www.fao.org/antimicrobial-resistance/key-sectors/food-safety/en/

services and households) was wasted ([35]). Cultural models of eating and attitudes towards food waste may drive food waste behaviour (Briones Alonso et al., 2018).

The economic and physical access – including affordability – to food is necessary, but not a conditions to ensure that people consume sustainable and healthy diets. ***Food choices*** are shaped by food environments, which encompass the physical, economic, political, and socio-cultural context in which consumers make decisions on acquiring, preparing and consuming food. Examples include food advertising, product placement, labelling, and the provision of clear information that enables consumers to make different dietary choices. A substantial proportion of the EU population appears to be predisposed to dietary choices that contribute towards environmental pressures on the food system and compromise population health. The consumption of meat in EU countries is, for example, often 2 to 4 times higher than the recommended intake (EC, 2021). At the same time, only 12% of the EU population consumed the recommended five portions or more of fruits and vegetables daily in 2019 ([36]).

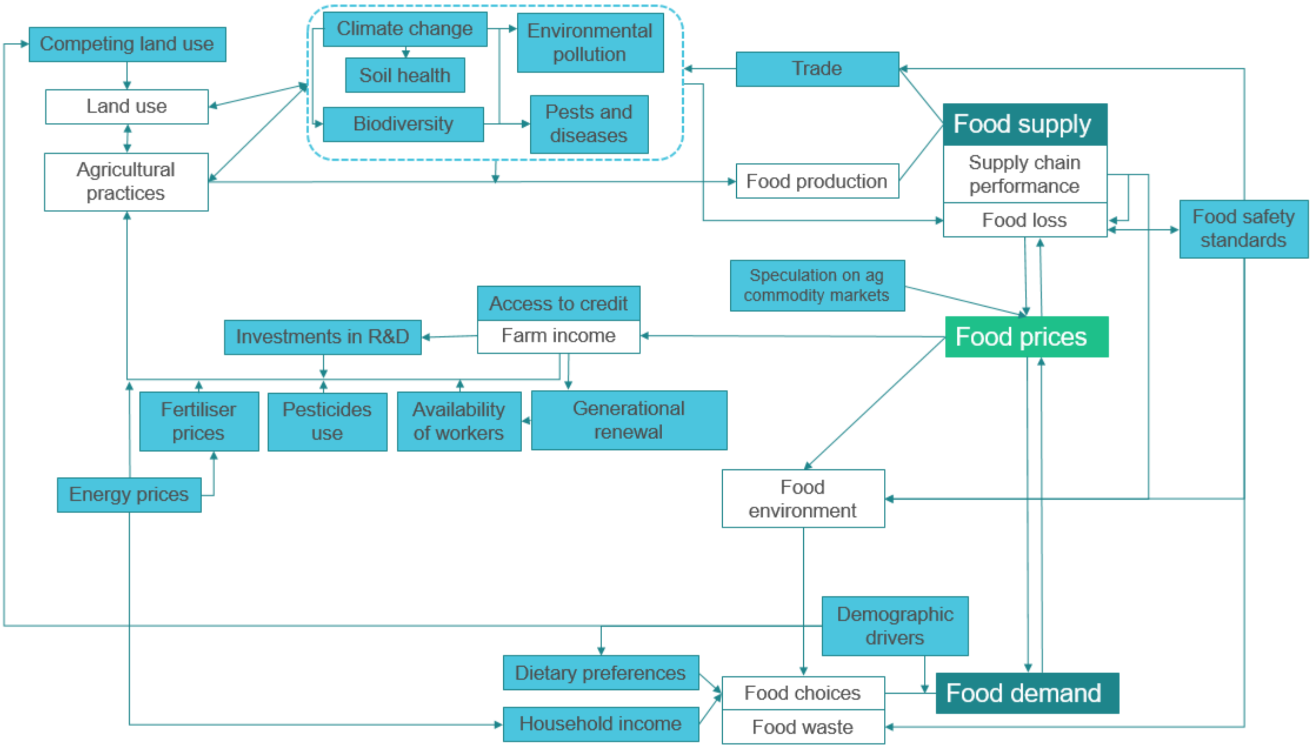
3.7. Demographic drivers

Demographic trends are crucial drivers of long-term food security. World population growth increases demand for food and agricultural commodities. Changing age structures of the population can also affect eating behaviour and thus the composition of food demand. Similarly, shifts in the distribution of the population across rural and urban areas is expected to lead to dietary change. Urbanisation can also affect food production as a declining rural population affects the availability of workers and hence the feasibility of different farming systems. While the global population is projected to continue growing until the 2080s, the EU-27's population is projected to peak to 449.3 million in 2026 and then gradually decrease (UN DESA, 2022. Similarly, while some Member States are expected to experience further urbanisation, the rate of growth in the proportion of the EU population living in urban areas is close to 0% (UN DESA, 2019).

([35]) https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Food_waste_and_food_waste_prevention_-_estimates

([36]) https://ec.europa.eu/eurostat/web/products-eurostat-news/-/ddn-20220104-1

4. Interlinkages between drivers of food security in the EU



The interlinkages between the drivers of food security in the EU are manifold and complex, especially when also considering indirect effects and interrelations. This section provides a brief summary, concentrating on the more direct interlinkages between the selected drivers. Figure 2 depicts the interlinkages between the different drivers reviewed in this note. As they are often interlinked because of their impacts on intermediate outcomes, these are highlighted in the figure.

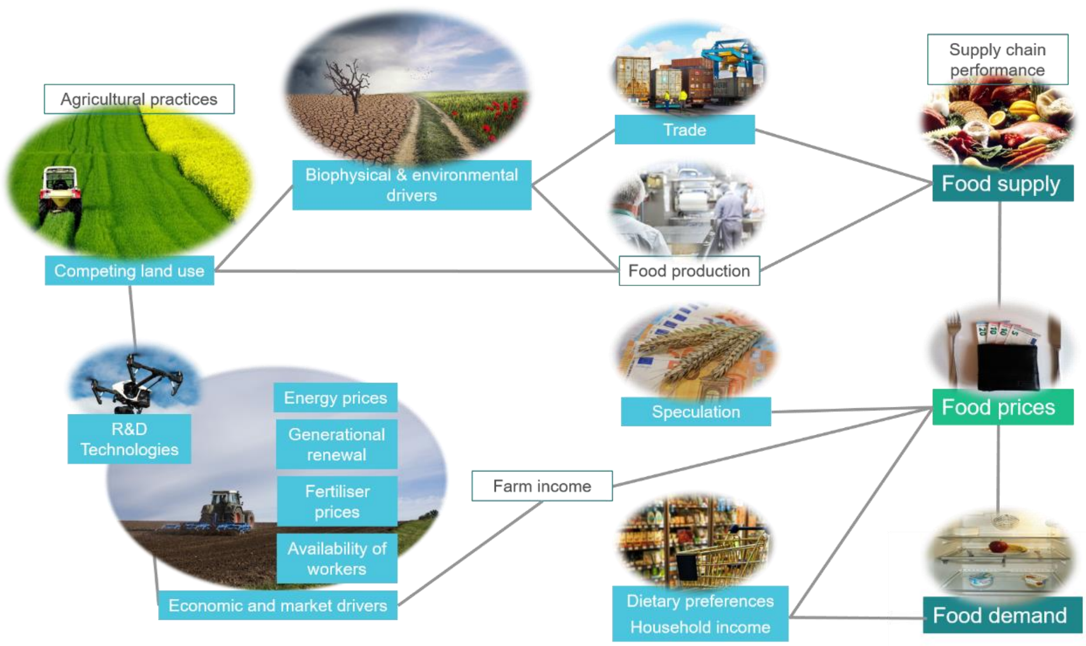


Figure 2: Interlinkages between drivers of food security

Note: Some of the drivers discussed in this note (i.e. farm income, supply chain performance, food loss, food waste, and food prices) can be considered both drivers and intermediary outcomes. They are highlighted as intermediary outcomes (in white) in this figure. The colour scheme further emphasizes the crucial role of prices, resulting from the balance of supply and demand.

Investments in research and innovation contribute and shaping which technologies and innovative practices are available and known to producers. Farmers' and fishers' resources, determined by ***farm income*** and ***access to credit***, the ***prices*** and ***availability*** of different inputs including ***energy***, ***fertilisers***, and ***pesticides***, as well as ***workers***, determine the intensity of the use of different inputs, technologies, and agricultural practices. This in turn affects productivity and the degree of ***sustainable production***.

Competing land uses, including for example the expansion of built-up areas shaped by ***demographic trends*** such as urbanisation, influence the availability of land for farming and for food production specifically. The availability of land will shape farming systems and also impacts the intensity of production. This relationship is, however, bidirectional as different farming systems will translate into different land use patterns.

The inputs used and other agricultural practices can have multiple effects on the biophysical and environmental drivers. The excessive use of agrochemicals, such as ***pesticides*** and mineral ***fertilisers***, and large machinery (e.g. intensive tillage) can have detrimental effects on ***soil health*** and ***biodiversity***. Emissions from farming activities also contribute to ***climate change***. This relation is again bidirectional. For instance, adverse effects of pesticides on biodiversity can increase crops' susceptibility to ***pests and diseases*** by reducing natural pest control, hence promoting more extensive use of ***pesticides*** unless alternative approaches, such as integrated pest management or agro-ecology, are promoted.

As illustrated by the example above, the different biophysical and environmental drivers are interlinked. ***Climate change*** is directly responsible for large ***biodiversity*** losses as species are unable to cope with unprecedented local environmental conditions. At the same time, biodiversity loss is affecting climate change (e.g. loss of carbon from degraded soil and from reduced forest coverage, drying peatlands and wetlands). Reduced species diversity and novel climatic conditions favour the spread of invasive alien species and outbreaks of ***pests and diseases***, with further detrimental effects on ***biodiversity***. ***Climate change*** also affects ***soil health***. Increasing rainfall intensity can result in higher soil and nutrient losses. Rising temperatures then again contribute to soil organic carbon loss (less fertility), peatlands degradation and CO_2 release to the atmosphere. In addition, ***climate change*** directly affects the risk of new plant ***pest*** outbreaks through shifts in pest habitats.

Ultimately, the farming systems, land use choices, biophysical and environmental drivers, determine how much food is produced. Food production is fundamentally determined by environmental drivers. Reductions in ***soil health*** and soil erosion reduce the amount of cropland available for food production. The increase in extreme weather events (e.g. droughts and floods) that comes along with ***climate change*** can have detrimental effects on crop yields or productivity. Agricultural yields are also impacted by air ***pollution***. The propagation of (new) plant ***pests and diseases*** also puts additional pressure on food production. More generally, a decrease in ***biodiversity*** and ***soil health*** can increase agro-systems' vulnerability to biological threats and ecosystem services that are crucial for agricultural production.

Food production, in combination with ***trade*** determines the food supply. It is worth noting that, if plant and animal health issues are not properly managed, international trade can also affect the spread of ***pests and diseases***. As the balance between food supply and food demand determines ***food prices***, all the drivers discussed so far are directly linked to food prices.

Not all food that is produced or imported will reach the consumer. Food has to be moved from production to consumers in the food supply chain, which includes activities such as storage, distribution, processing, packaging, retailing and marketing. ***Well-performing supply chains*** and good infrastructure ensure an efficient movement of food up to the final consumer with minimal ***food loss and waste***. In addition, ***climate change*** is expected to aggravate food loss. Again, investments in R&I contribute to shaping which technologies are available for reducing food loss throughout different stages of the food supply chain. The costs associated with these activities, which will again be affected by ***energy prices***, directly influence ***consumer food prices***.

Consumer prices and availability of different foods, as well as promotion, advertising, and information, are crucial elements in the food environments. Together with ***household incomes*** and dietary preferences, these shape individual and household ***food choices***. The food choices ultimately aggregate into food demand. As such, dietary preferences and household incomes can influence food prices. It is worth noting that food wasted at consumer level also affects total demand for food. The food environment, ***consumer food prices*** as well as ***household income*** are likely to shape ***food waste*** behaviour. In addition awareness raising campaigns or private market advertisement may also have an influence (positive or negative). The aggregation of individual and household food consumption (and waste) into overall food demand is affected by ***demographic trends***, such as population growth and urbanisation.

Energy prices play a particularly important role in the entire food system. The consumption of energy is a function of its price, and changes in energy consumption can affect ***climate change*** *and* ***environmental pollution***. Energy prices may also affect ***land use*** as they can influence the (relative) profitability of biofuels production. In addition to the direct effect on farmers' and other supply chain actors' costs based on their energy use, changes in energy prices can alter fertiliser production and ***fertiliser prices***. Furthermore, changes to energy prices influence operational costs and the ***functioning*** of all actors in the ***food supply chain***. Energy prices also influence ***households'*** disposable ***income*** and hence the budgets available for purchasing food. Integrating renewable energy sources in rural areas such as agro-voltaic, wind farms, biogas, and biomethane production based on sustainable feedstock and other sustainable bioenergy solutions in rural areas would aid to alleviation of the above mentioned energy challenges, mostly attributed to the fossil sources or long supply chains. In addition, engaging low-value biomass for bioenergy in integrated systems for circular bioeconomy would add to food resilience as well ([37]).

([37]) Schipfer, F.; Pfeiffer, A.; Hoefnagels, R. Strategies for the Mobilization and Deployment of Local Low-Value, Heterogeneous Biomass Resources for a Circular Bioeconomy. *Energies* **2022**, 15, 433. DOI: 10.3390/en15020433

5. Short-term and long-term trends

Both short- and long-term trends of drivers threaten the viability and resilience of the food system by reducing its future capacity to face, respond to, and adapt to disturbances and shocks ([38]).

This analysis does not explicitly separate short- and long-term drivers as they generally both impact current and long-term food security. Both aspects are highly interlinked and to a certain degree inseparable. While long-term drivers determine trends, short term shocks are part of this trend and often bear long-term consequences. At the same time, long-term drivers can themselves bring short-term shocks – the drought in large parts of Europe of 2022 being an example.

Short term shocks typically affect the ***stability dimension of food security***. Short-term shocks are often the result of changes to ***household income*** (such as reduction in amount and/or increasing costs) or disruptions in food supply. Temporary income reductions can derive from conflict, natural disasters, and those of a more individual nature, such as illness or unemployment. The extent to which such shocks translate into reduced economic access to food is a function of social protection and safety nets in place. Disruptions to agricultural production can stem from factors such as ***conflict, and natural disasters***, or sudden increases in ***energy*** or ***fertiliser prices***. Temporary disruptions and bottlenecks may also hamper the functioning of the ***supply chain*** and thus reduce its capacity to bring food to the consumers, and abrupt changes in ***trade*** policies such as the implementation of export bans, also affect the supply of food.

Since the Russian invasion of Ukraine, there is an increasing focus on the short-term shocks and possible long-term consequences. This ***conflict*** has immediate disruptive effects on ***food production, supply chains, markets*** and ***trade***, thus worsening food availability and access, and causing spikes of acute food insecurity and displacement. To make matters worse, conflicts exacerbate and prolong the impacts of other shocks such as extreme weather events or food price spikes.

Ukraine is one of the world's biggest exporters of key agricultural products. The impact of the war, including the blockade of Ukraine's food exports through the Black Sea ports in the first months of the war, has seriously jeopardised food supply to some of the most vulnerable parts of the world (WTO, 2022) ([39]). The signature of the 'Black Sea Grain Initiative' by the United Nations, Turkey, Ukraine, and the Russian Federation on 22 July 2022, and its further extension with 120 days after November 2022, together with the functioning of the EU Solidarity Lanes eased the pressure on international commodity prices. These allowed the resumption of Ukrainian grain exports amid the ongoing war.

Food inflation in particular reached the level of 18% in October 2022, second only to energy as the largest contributor to the EU inflation rate, and affecting particularly prices of essential food items such as bread, milk, eggs, and cheese as well as oils and fats. Rising production costs, along the whole food supply chain (e.g. electricity, processing, packaging, transport, cooling and heating), pose difficulties for all businesses, though small- and medium-sized enterprises are particularly hard-hit. Producer prices of agricultural commodities are expected

([38]) https://www.un.org/en/food-systems-summit

([39]) Ukraine solidarity meeting - Joint statement (europa.eu) to continue weighing on consumer prices, remaining historically high despite a decline observed in summer 2022 following the reduction of commodity prices.

For EU consumers and producers, the most noticeable impact of the conflict is on ***energy*** markets, in particular natural gas. The price of natural gas in the EU reached new record levels in summer 2022, leading to additional input costs for the EU food supply chain and further fuelling inflation and consequently limiting food choices.

Linked to the energy price surge, another major concern for agriculture is the availability and cost of ***fertilisers*** for the upcoming season 2023. Fertiliser industries need natural gas to produce ammonia and other nitrogen products, and they can reduce or halt production when gas prices are too high. Farmers are under the double pressure. On the one hand processors and distributors want to preserve their operating margins, and on the other hand consumers are facing increasing costs of living that may result in reduced food demand and different food choices. All these pressures linked to the increasing costs put into question the viability of many farmers.

Looking at specific ***EU agricultural markets*** ([40]), a combination of the exceptional 2022 summer drought and high fertiliser prices resulting in lower application rates of phosphorous and potassium in particular, also contributed to lower yields for the 2022/23 harvest. As a result, total EU cereal production is now forecast to be 7.8% lower year-on year, with maize showing a staggering –23.7% reduction in production. However, thanks to higher ending stocks in 2021/22, EU cereal exports could still grow (+6.5%), and therefore continue to contribute to global food security.

Even if recent crises showed that the current EU food system has been rather resilient to various shocks, they have also exposed its vulnerabilities by highlighting the need to halt and reverse the underlying non-favourable long-term trends. The food system, particularly during the COVID-19 pandemic, showed a good capacity to face disturbances and to adjust the production processes, distribution, and logistics. However, it also showed that its capacity to withstand and adapt to disturbances varies widely across its various components, regions, and over time (e.g. with respect to poverty and hunger of vulnerable groups, loss of income and livelihoods, shift to unhealthy diets, increased food insecurity in developing countries) (Deconinck et al., 2021; McDermott and Swinnen, 2022).

The food system, particularly from the production perspective, is strongly dependent on ***environment and climate conditions***, both of which interact with food security. Environmental and climate conditions unfavourable to food production can take years to emerge, and equally call for long periods if they are to be reversed and repaired.

Climate change is a key driver of the long-term trend in food production and it affects harvest and consequently production, in particular crop production, in Europe and the world. We observe increasing weather extremes, droughts and shifting climate zones affecting crop production patterns as we saw in 2022. Several unprecedented drought and floods events hit Europe in recent years with varied impact on different regions and crops. So far, a **functioning EU common market** provided protection against regional production shocks. Even in the best-case mitigation scenario, climate change impacts in Europe and the world will further worsen

([40]) EC (2022), Short-term outlook for EU agricultural markets, Autumn 2022. European Commission, DG Agriculture and Rural Development, Brussels in the coming decades, while the probability of synchronous global failures of major crops is projected to become significant ([41]).

Water in the EU is becoming scarcer, both temporally and spatially, and this together with higher temperatures, increases irrigation needs and water deficits. Large-scale concurrent climate extremes may simultaneously hit major agricultural production regions. Of all sectors, agriculture is hardest hit by climate change, and the Mediterranean will suffer particularly. However, the food system also has significant impacts on climate change with food system emissions accounting for 25-30 % of overall GHG emissions. Decreasing food systems-related greenhouse gas and pollutant emissions will contribute to long-term food security. Impacts of climate change on fisheries are subject to a high complexity, and climate change scenarios show moderate yield declines with high uncertainty.

Currently ***air pollution*** (ozone and aerosol) negatively affects crop yields with an estimated reduction of 5-10% of the EU wheat production. In the long-term ambitious air pollution legislation can substantially reduce air pollution impacts. The EU methane strategy, and similar global methane emission reduction strategy could further reduce crop losses by 2-7% in Europe.

Chemical pollutants (e.g. nutrients), and (micro-)plastic contaminate freshwater for drinking and irrigation- and affect production levels of freshwater and marine ecosystems. The Zero Pollution Action Plan provides encompassing targets for 2030 for environmental pollution-aligned with EGD initiatives on climate change, biodiversity and circular economy

Soils are the basis for agricultural food production and act as buffers against climate change risks, such as floods and droughts. Unhealthy soils will produce less. About 60-70% of EU's agricultural soils are currently either losing organic carbon, receiving more nutrients than they need (affecting also water resources and natural habitats), eroding or compacting, suffering secondary salinisation, or some combination thereof. Long-term trends of the underlying drivers of soil degradation are not subjected to change favourably. Climate change induced changes will further contribute to erosion and loss of soil organic carbon.

Pests and diseases negatively impact food production and food availability. The FAO estimates that 40% of food crops are lost globally due to plant pests and diseases every year. In the long-term, the severity of the impacts is expected to increase with rising temperature patterns in Europe, and farmers need to put in place strategies to reduce them. Spikes in the energy and fuel prices may result in, for example, mechanical weeding being a less attractive alternative to herbicides, making chemical crop protection more competitive. In the long-term, there is consensus in the public domain and in academia to move away from pesticide-centric food systems and the availability of alternative solutions to widespread chemical plant protection products is expected to widen. A transition must build on the diversity of knowledge on complementary strategies for crop protection as in the integrated pest management principles. Advances in analytical capabilities will allow for more targeted, applications of pesticides

Biodiversity makes food production systems and livelihoods more resilient to shocks and stress, including those caused by climate change, but the biodiversity loss is grave. The FAO estimated that 75% of the varietal genetic diversity of agriculture has been lost in one century. Such a genetic erosion of our nutritional base has considerable implications for food security, since

([41]) See e.g. Tigchelaar et al (2018), 'Future warming increases probability of globally synchronized maize production shocks', Proceedings of the National Academy of Sciences, 115(26); Gaupp et al (2020) Changing risks of simultaneous global breadbasket failure | Nature Climate Change relying on a narrow genetic base for nutrition makes food systems more vulnerable (Sunderland, 2011).

The limits of the Earth's ecosystems in relation to biodiversity and climate have already been exceeded ([42]). In 2020, with food representing around 45% of the environmental impacts of EU consumption, the EU food system alone transgresses several planetary boundaries ([43]), including climate change (3.5 times), particulate matter (6 times) or freshwater ecotoxicity (5 times) (Sanyé Mengual and Sala, 2022). Similarly, the biogeochemical flows of the nitrogen and phosphorus cycles have surpassed the planetary boundaries by 3.3 and 2 times ([44]). This seriously compromises the long-term viability and resilience of the food system regarding its environmental foundation.

For the food system to withstand and adapt to disturbances across its various components, regions, and over time sustainable food system approaches, including management of excessive emissions of nutrient and air pollutants, reducing carbon emission, and improving resilience to climate change are needed.

In this context ***Research and Innovation, and technology*** is one of the keys to enabling food systems transformation and allow operators cope in a successful way with both short and long term challenges. Harnessing the potential of diverse forms of innovation and technologies also requires investments in human capital and knowledge flows (education, training, etc.). This is an important long-term investment as close to 70% of all EU farm managers did not receive any formal agricultural training. R&I related to food systems also developed solutions relevant to food security and resilience, including on the reduction of food losses, waste reduction, and diversification of diets through the production and provision of food and ingredients based on alternative sources of protein (e.g., plant-based or ocean-based).

Short-term shocks, such as the energy price increases and agricultural commodity shortages experienced as a result of Russia's war against Ukraine are highly visible, affect vast swathes of the population, and almost always impart a sense of urgency in terms of response from policymakers. However, short- and long-term drivers are inextricably intertwined: the state of the food system is the result of a delicate balancing act between the decision taken in the past, and present and consideration of future goals. Acting only on the now, without considering what came before and what will come next is no guarantee for a safe, sustainable, and secure food system on which we all depend.

6. Focus on key drivers in low-income countries

The discussion has so far centred on food security and its drivers in the context of the EU. As food security is complex and the importance of and interlinkages between different drivers is highly context-specific, this summary should not be generalised to other parts of the world. In this section, the analysis highlights some notable facts about the drivers of global food security

([42]) Rockström, J., Steffen, W., Noone, K. et al. A safe operating space for humanity. Nature 461, 472–475 (2009). https://doi.org/10.1038/461472a; Steffen et al.: Science, 201, DOI: 10.1126/science.1259855

()([43]) The assessment is performed at a per capita level, with Planetary Boundaries allocated equally among the global population.

([44]) https://www.eea.europa.eu/publications/is-europe-living-within-the-planets-limits with particular attention to the context of low-income countries as they are home to most of the world's food insecure population.

From a global perspective, demographic drivers affecting patterns of both food production and consumption are particularly important for food security. The question of population growth has long been connected with the topic of food security. While the global population growth rate is declining, the world's population is projected to grow to around 8.5 billion in 2030 and reach a peak of around 10.4 billion people during the 2080s. More than half of the population increase projected through 2050 will derive from Sub-Saharan African countries (UN DESA, 2022). In the context of a growing population with growing food demand, global food production will have to continue to increase, though by how much will depend on consumer food choices and the ability to reduce food losses and waste. While the most often cited required rate of increase of food production is 60% (Alexandratos and Bruinsma, 2012), other studies point estimates between 35% and 56% (Van Dijk et al, 2021).

The spatial distribution of the population within countries is expected to change as well. While an estimated 57% of the global population is living in urban areas today, this is expected to rise to 68% in 2050 (UN DESA, 2018). Urbanization is often expected to put additional stress on food systems by changing food demands. Often-cited changes includes an increased consumption of processed and animal-source foods. Yet, the understanding of urbanisation as a driver of changes in food consumption remains limited (Cockx et al., 2018). Rapid urbanisation in low-income countries and rural-urban migration flows have also given rise to concerns about the availability of (young) workers for farming. The importance and effects of these migratory movements are, however, diverse and context specific (Cattaneo and Robinson, 2019). More generally, the fear of a mass exodus of youth out of agriculture in low-income countries does not appear to be supported by the evidence (Mueller 2021; Christiaensen et al. 2020).

As mentioned above, the pathways through which several drivers affect food security and their relative importance can be significantly different in low-income countries. A first notable fact is that the majority of the food insecure population in these countries resides in rural areas and depends on farming for most of their income. This is especially true in Africa. As such, the distinction between farm income and household income is much less clear. It is worth noting, however, that also smallholder and subsistence farmers also rely on food purchases for a substantial part of their consumption (Sibhatu and Qaim, 2017; Frelat et al, 2016). Farm income is therefore a direct and crucial determinant of many households' economic access to food in low-income countries. Although, according to official figures, it may appear that Africa, for instance, is 80% food self-sufficient (OECD/ FAO 2021 report). This is due to the fact that agriculture is based on family farming, with reduced input, investments and infrastructures, while the low levels of imports are largely due to poverty, in particular in rural areas, resulting in food insecurity.

Moreover, as these households are often both producers and consumers of food, the impact of increasing food prices on access to food is highly complex. For households that are net sellers of food, the positive effect of food price increases on farm gate prices and income may outweigh the negative effect on the increased cost of purchased food. The same holds at the macro-level (Swinnen, 2011). Self-reported food security in Africa, for example, improved for net food producers over the period 2005–2008, when global food prices increased dramatically. This was observed both at the micro-level, among rural households, and macro-level, among net food exporting countries (Verpoorten et al., 2013). For countries depending on food imports and subsidising bread, the high share of food in the overall national economies means a high exposure to food insecurity drivers increasing fragility and costs for subsidies with rising food price.

While data is scarce, food loss tends to be a particularly serious problem in low-income countries because of poor drying and storage handling or weak postharvest infrastructure. In the context of low-income countries, reducing food loss (especially on-farm losses) would not only contribute to food availability, but also to income growth and therefore food access. The rate of food loss was estimated at 21.4 % for sub-Saharan Africa in 2020 ([45]). While this reflects the physical quantity of food lost, the value and revenue losses associated with releasing harvest onto the market early in order to limit losses due to poor storage facilities may be much larger (Sheahan and Barrett, 2017; FAO, 2021). In addition, food losses tend to be higher for highly perishable micronutrient-rich foods such as fruit and vegetables. Especially in the context of low-income countries where farmers lack access to cold storage and other infrastructure, this is likely to influence crop allocation decisions and hence the availability of micronutrient-rich foods.

While there is much debate about the exact estimates of agricultural input use in sub-Saharan African countries, it is well-acknowledged that modern input use is relatively low in aggregate. This holds in particular when also considering irrigation and mechanised equipment (e.g. Sheahan and Barrett, 2017). Many countries in sub-Saharan Africa also depend heavily if not completely on imports for their use of agricultural inputs. For all but four countries in the region for which data for 2019 is available, domestic use of fertiliser was fully supplied by imports ([46]). This import dependency renders them particularly vulnerable to price increases on world markets. In addition, their relatively lower use of agricultural inputs implies that these countries are smaller markets that are likely to be bypassed by producers and traders in case of limited supplies ([47]). Another issue affecting food systems in many Sub-Saharan Africa's countries is poor governance and lack of regulation, which disincentives private sector's investments and brings about land grabbing, deterioration of productive land and biodiversity and sub-optimal allocation of financial resources.

In Europe, biophysical and environmental drivers have a major influence on food security worldwide. Biodiversity loss is undermining the foundation of global food systems, including through decreasing plant diversity in farmers' fields, rising numbers of livestock breeds at risk of extinction and increases in the proportion of overfished fish stocks. Of some 6,000 plant species cultivated for food, fewer than 200 contribute substantially to global food output, and only nine account for 66% of total crop production ([48]). Three-quarters of the world's crops depend on pollinators to some extent.

([45]) FAO (2022). Food Loss and Waste Database. Available at https://www.fao.org/platform-food-loss-waste/flw-data/en/

([46]) Laborde, D. (2022). Fertilizer dashboard. Available at https://public.tableau.com/app/profile/laborde6680/viz/Fertilizer_Dashboard/FertilizerDashboard

([47]) Hebebrand, C., Laborde, D. (2022). High fertilizer prices contribute to rising global food security concerns. IFPRI Blog. Available at https://www.cgiar.org/news-events/news/high-fertilizer-prices-contribute-to-rising-global-food-security-concerns

Challenges such as desertification, land degradation, and water scarcity are particularly affecting food security globally. Desertification affects around 45 % of Africa's land area, with 55 % of this area at high or very high risk of further degradation. It is often considered that land degradation in Africa has been vastly detrimental to agricultural ecosystems and crop production and thus an impediment in achieving food security and improving livelihoods ([49]). Unsustainable water management and climate change, coupled with increasing demand for water from growing populations are increasing competition and reducing access to clean water, groundwater and sustainable irrigation. In addition, it is observed that across sectors and regions, human-induced climate change, including more frequent and intense extreme events, disproportionally affects the most vulnerable people and systems ([50]).

Finally, the negative effects of conflicts on global food security, nutrition and primary production are uncontested ([51]). Organized violence and conflict remain the primary drivers of acute hunger. In 2021, 10 countries were home to 70% of people experiencing acute hunger. In seven of these, conflict was the primary driver of acute food insecurity. It is worth noting that food insecurity can fuel conflict as well. Food price rises, for example, have been shown to be associated with increases in social unrest (e.g. Bellemare, 2015).

7. Conclusions

This analysis laid out the challenges ahead for the EU at global level when facing the different dimensions of food security. While the assessment confirms that the availability of food is not at stake in Europe today, the affordability of food is a growing concern for an increasing number of low-income households. The trends and the combination of drivers draw attention to the fact that availability, access (affordability), utilisation, and stability cannot be taken for granted in the short or the long term, and that some of these drivers may become risks for food security and expose vulnerabilities in our food system, if not properly addressed.

In the short term, the Russian invasion of Ukraine had immediate disruptive effects on food production, supply chains, markets, and trade, thus worsening food availability and access (affordability), and causing acute food insecurity in some third countries. In some parts of the world, this had led to conflicts, and exacerbated and prolonged the impacts of other shocks, such as extreme weather events or food price spikes. Current pressures on production costs and producers' income in a context of a growing decline of the farming population need to be taken into account to guarantee production capacity.

The analysis confirms that the production is facing increasing pressure on natural resources (water scarcity, pollution, decreasing soil fertility, and air pollution), pollinators decline, pests and diseases, reduction of biodiversity and ecosystem services as well as the multi-facetted impacts of climate change. If not duly addressed with urgency, this will limit the production necessary to provide food to an increasing world population. While chemical/synthetic

([50]) Masson-Delmotte, V. et al. 2021. IPCC, 2021: Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I.

([51]) https://www.wfp.org/publications/global-report-food-crisis-2017 pesticides contribute to stabilising yields in the short-term, their use and risks needs to be progressively and smartly reduced to avoid detrimental effects on the utilisation and stability dimension of food security in the mid- to long-term, while preventing further environmental degradation, and thus promoting resilient food systems.

Regarding the access (affordability) dimension, special attention needs to be paid to low-income households that are not able to access diverse, healthy, and nutritious food due to the expected persistence of high levels of food prices and high energy prices in a context of low economic growth or even recession in some countries in the short-term.

The analysis highlights the complexity of any debate about food security: it is not a matter of prioritising one driver over another, rather it is important to understand the short- and long-term dimensions of the drivers and their interlinkages. By definition, food security has a short-term dimension: people must have access to food every day, not only tomorrow. This requires policies that enable food security in all its four dimensions to be guaranteed in the short run.

At the same time, the analysis also recognises that the ability to ensure food security in the long-term requires policy interventions that reinforce sustainability and resilience of the food system in view of the pressure on climate or natural resources. The real challenge for policymakers is therefore to pave the way for a transition towards a sustainable and resilient food system, which meets and reconciles time short and long-term needs at the same. A systemic approach is needed, which is capable of embracing this complexity. A broad range of actions across many policy areas, from agriculture, fishery, and aquaculture, to health, social, trade, climate, environment, energy, research and innovation etc., must be coordinated and integrated in a way that considers the interplay of the different drivers and is capable of identifying and addressing existing and potential future trade-offs. At the same time, a range of factors across the food system, including impacts on terrestrial and marine biodiversity, production practices, technology, processing methods, supply chain/logistics, food environments, consumption, social innovation, etc. will have to be adapted to live up to the ongoing and future challenges.

In that process, research and innovation, technological development, knowledge transfer and reskilling are key enabling factors to achieve higher efficiency on food production while minimising the effects on natural resources. These drivers are pivotal to coping with some trade-offs identified among other drivers, and to providing ways forward that can allow producers to adapt to long-term challenges while minimising short-term potential negative effects. The timing for the development of the most advanced technological solutions and their uptake among producers are among the most pressing challenges in the food security debate.

A coordinated and comprehensive approach also requires strong governance at different levels (EU, national, regional, and local), with a common understanding of sustainability and responsibilities being shared by all actors of the food system across the value chain. Concentrations of power upstream and downstream have reduced efficiency and fairness of food supply chains, with primary producers and consumers bearing the costs. A well-functioning food system that also integrates in the value chain environmental externalities will require action to better organise and structure the food value chain, especially by empowering the most vulnerable actors, including consumers.

In the global context, the EU is a significant producer and exporter of agricultural goods, making it an essential actor to contribute to global food security. Although mainly oriented towards the export of high value-added food products, the EU also plays a major role in supplying staple food, such as grains, to import-dependent third countries, in particular developing countries. The EU is also one a major global donor providing very significant food humanitarian aid and development cooperation financing in support of food security and agriculture in partner countries. As seen during the COVID-19 pandemic, and more recently in the context of addressing the global consequences of Russia's war against Ukraine, cooperation with partners is essential to safeguarding food security at all times. In an increasingly interconnected world, there is a need to ensure effective multilateralism, support diversification, increase market transparency, and avoid trade-restrictive policy measures. In the wake of Russia's aggression against Ukraine, the EU has demonstrated its importance to global food security by boosting trade to import-dependent countries with a considerable increase in food exports to Middle East and North Africa, as well as sub-Saharan Africa, compensating for lower shipments via the Black Sea.

The COVID-19 pandemic and Russia's attack on Ukraine provide further arguments in favour of fortifying food systems. E.g. the energy crisis confirms the need to move away from fossil fuel-based fertilisers; and extreme climate events urge cutting emissions and scaling up nature-based approaches. At the same time, the drivers of climate change, biodiversity loss, ecosystem collapse, and resource scarcity are some of the biggest threats facing humanity in the next decades. The costs of inaction hugely outweigh the costs related to the transition. A precondition for food security is an agricultural- and food system that is sustainable across all dimensions – economic, environmental, and social.

The analysis underlines that there is an inherent urgency to act. In an uncertain and volatile context, the transition to a sustainable food system should continue to guide the EU's political, policy, and programme action.

The present analysis will provide a framework for Commission services to ascertain and weigh the manifold dimensions relating to food security in taking forward relevant policy initiatives.

A consistent and comprehensive implementation of the European Green Deal, including the Farm to Fork, Biodiversity and other relevant strategies, should help the EU secure a sustainable, inclusive and resilient food system within a realistic timeline and with necessary support instruments.

The Common Agricultural Policy, in particular, as well as the Common Fisheries Policy, will continue to support the EU's farming and fishery communities, including in the transition towards a more sustainable farming and fishery model, which better preserves the natural resources. This will help ensure food availability and food access for consumers at reasonable prices as enshrined in the TFEU. Leading by example, using its internal market and its global trade relations and partnerships to leverage global standards, the EU can promote ambitious food systems strategies through partnerships across the world. This would follow the pathway indicated by 2021 UN Food Systems Summit and the 2030 Agenda for Sustainable Development.

8. Analysis of the individual drivers

8.1. Climate change

General context and what is at stake?

Climate change is a confounding factor that can affect agriculture and food security in many different ways. Climate-resilient food systems are needed to ensure food security and to support mitigation efforts.. Climate projections indicate temperature changes in Europe of some 2-5 °C in the scenario of a global temperature increases of 1.5 °C (very likely to be reached in the next decades without more ambitious and effective global GHG mitigation (Masson-Delmotte et al. 2021), with a 50-50% chance of at least one of the next five years exceeding 1.5°C above pre-industrial levels (World Meteorological Organisation, 2022) These changes have already caused, and will continue to cause, a marked north-ward movement of agro-climatic zones in Europe between 50-150 km per decade (Ceglar et al. 2019). Similar northward displacements are observed in the marine environment. At the same time, the EU and global food systems are major drivers of climate change, with about 30 % to the overall anthropogenic GHG emissions (Crippa et al. 2021). EU emissions from the agricultural sector have not substantially declined during the last decades, and the land use sector has lost some of its capacity to act as a carbon sink (EEA 2022)

Water of sufficient quantity and quality is key to food security. Average precipitation rates are projected to decline in the Mediterranean region, while increasing in Northern Europe (Ranasinghe et al. 2021). In addition, a larger fraction will fall as heavy precipitation across most areas of Europe. There will be further increases in the frequencies and intensities of extreme weather events, particularly as regards droughts and heat waves (Seneviratne et al. 2021; Toreti et al. 2019; Vogel, Hauser, and Seneviratne 2020). With 40 % agriculture is the biggest water consuming sectors in the EU (reaching 80 % in Mediterranean countries) and a major cause of pressures on water resources. The availability of water is becoming scarcer, both temporally and spatially, and this together with higher temperatures, increases irrigation needs/water deficits (Gelati et al. 2020) and the amount of energy and operating costs needed for irrigation are expected to increase. Illegal abstraction and increasing salinisation are exacerbating the problems.

Food security issues related to climate change in fisheries are linked to the availability of marine re-sources, the stability of supply, the access to food, and the utilisation, i.e. the change in food/feed use (HPLE 2014; KCFNS 2020), the state of the stock and the governance globally. The Intergovernmental panel on climate change (IPCC) assessments indicate that climate change impacts will be disruptive for marine ecosystems, economies and societies, especially in those regions that are highly dependent upon natural resources.

Current assessment – 2022-24

While higher levels of atmospheric CO_2 may enhance photosynthesis and growth in some crops (Toreti et al. 2020), there exists no clear picture on the overall effects on crops. Further, it has been reported that plants grown under higher CO_2 levels have changed nutritional value (Dong et al. 2018).

The frequency and intensity of droughts have increased over the last 30 years in many areas of the world, e.g., the Mediterranean (EC 2012; UNDRR 2021). Unprecedentedly extreme droughts have re-cently occurred also in other parts of Europe.

Depending on the region, between 39-60% of the financial losses from climate change impacts relate to agriculture. Increasing water stress, due to climate change, unsustainable water use practices and the competition between different sectors (in particular agriculture and energy) poses a threat to food production. Even if available, the quality of available water re-mains a critical issue to be tackled.

Crop losses in the EU due to increasingly frequent droughts are currently estimated by PESETA IV to be at around EUR 9 billion/year (with the highest losses in Spain – EUR 1.5 billion/year, Italy - 1.4 EUR billion/year, and France – EUR 1.2 billion/year (Feyen et al. 2020)

Water stress already affects about one third of the EU territory all year round, not only arid or densely populated regions in southern Europe, but northern European countries also face seasonal water stress, including Belgium, the Netherlands and Germany. The increasingly seasonal variability of water availability will also require Northern countries to step up their management of water resources (EC 2012). The use of groundwater in some regions has surpassed sustainable levels (Gelati et al. 2020; de Roo et al. 2021), often exacerbated by illegal abstraction.

Currently, the impacts of climate change and extreme weather events on agricultural production have been limited to specific regions (Baruth et al. 2022). However, this situation is changing. High impact concurrent/compound events poses a threat to the agricultural production (Chatzopoulos et al. 2021). Persistent drought conditions (winter-to-summer) associated with recurrent heatwaves is causing huge losses across the agricultural sectors both for winter and summer crops, as well as livestock (Toreti et al. 2022). While there is consensus on the overall estimates of climate change im-pacts, substantial research efforts are needed to improve the predictive skills of weather forecast and climate models on the seasonal to decadal time scale, and enhance their usability for targeted adaptation strategies in agriculture and other sectors.

In support of the EU’s adaptation strategy, the Mission on Adaptation to Climate Change (DGRTD 2022) supports about 150 EU regions to build resilience against climate change, by better understanding cur-rent and future climate risks, develop pathways to increase resilience against climate change impacts, and test innovative solutions.

Forward looking - 2030

According to IPCC (Pörtner et al. 2022), effective adaptation strategies- supported by policies, reduce climate risks for food systems and enhance food availability and stability, and increase their sustainability. There are many adaptation options (e.g. cultivar and other technological improvements, farm and landscape diversification, nature-based solutions, and changing farming systems), but their potential effectiveness depends on their local agro-environmental and socio-economic context. Targeted climate services (Buontempo et al. 2022) are an important component of effective adaptation strategies, but predictive skills need to be improved to ensure their effective implementation.

Climate change is expected to exacerbate the already existing pressures on EU water resources, with overexploitation often related to a lack of governance. In water stressed areas, intensive groundwater pumping for irrigation could result in depleted aquifers and can lead to significant economic and environmental impacts on the sector and beyond. There is scope to reduce the water use in agriculture, but currently planned measures by Member States to increase the irrigation efficiency are not sufficient to tackle the impacts of climate change as anticipated in the climate projections (de Roo et al. 2021). Investments need to be increased and new practices employed, particularly in the Mediterranean region. For instance, integrating agro-voltaics in vineyards and orchards as water collection surface during the rainy season and shade to prevent evaporation during the heat days, reduces water demand. The re-use of water can be an important measure to reduce abstractions and can hence protect ecosystems and other water users. The costs of treatment for re-use —as per the new EU standards — may however exceed the current willingness to pay for water in agriculture (de Roo et al. 2021) , calling for policy innovation to align short-term economic incentives with longer-term physical constraints Desalination could be an increasingly attractive approach to reducing water scarcity. It is essential that it is put on track to be carbon-neutral — which is feasible — and coupled with re-use for irrigation in order to maximise its benefits (de Roo et al. 2021).

In the absence of adaptation, assuming that the current irrigation practices would still be possible, cli-mate change is expected to substantially lower grain maize and wheat yields in southern Europe, and to a lesser extent grain maize yields in northern Europe. In this case, EU production could still slightly increase due to the interplay of international trade markets. Grain maize yields in the EU are projected by multiple crop models to decline by 2050 between 1% and 22% due to changes in daily temperature, precipitation, wind, relative humidity and global radiation (Hristov et al. 2020). However, as sufficient quantity of water for irrigation will not be available, maize production will become unsustainable in Southern Europe (yield declines by >50 %). In addition, by 2050 wheat yields in Southern Europe are expected to decrease by up to 49%, but potentially increase in Northern Europe. In the coming eight years, the European wheat and maize production will become even more vulnerable to unfavourable climate conditions and extreme weather events (heatwaves and drought (Chatzopoulos et al. 2021)), and global markets could be highly affected by climate extremes.

Changes in frequency and intensity of regional climate extremes, such as heat waves, droughts, and heavy precipitation scale with global warming levels. Climate projections point to an accelerating in-crease in the frequency and intensity of weather extremes between 2031-2060 (Seneviratne et al. 2021), such as droughts, with early signs expected in the next years to decades. Unprecedented droughts may hit key agricultural regions of Europe and the world (UNDRR 2021).

There may be large consequences for regional agriculture production and food habits. For instance, between 2031 and 2060, major durum wheat-producing regions in Italy, France, Ukraine, USA and Canada may become climatically unsuitable (Ceglar et al. 2021), corresponding to a 19 % loss by the mid-21st century, of the land climatically suitable to grow durum-wheat.

Climatic factors affect the biotic and abiotic elements that influence the numbers and distribution of fish species. Among the abiotic factors are water temperature, salinity, ocean acidification, nutrients levels, sea level, extent and amount of sea ice (KCFNS 2020). Biotic factors include food availability and the presence and species composition of competitors and predators. Identifying the relationship be-tween climatic factors and the fish-carrying capacity of the marine environment is challenging, owing to complex oceanic food webs and mobility of species. Therefore, projections of total future fishery yields under climate change scenarios only show a moderate decrease with high uncertainty. Geo-graphic distribution of fish species may also change due to climate change. However, there are dramatic regional variations with some regions likely to suffer a strong decrease in fisheries yields while other showing slight increases. Largest socio-economic and food security impacts will occur in regions which are highly dependent upon natural resources (Bindoff et al. 2019; Cooley et al. 2022).

International dimension:

Large-scale concurrent climate extremes, such as drought and heatwaves, may hit key agricultural producers of the world triggering market shocks, higher volatility and price spikes in the coming dec-ade. In 2050, climate change (RCP 6.0, SSPs 1-3) is expected to induce a 1–29% cereal price increase (Mbow et al. 2019). Climate extremes may significantly distort agricultural market equilibria in the coming decade. Extreme global food prices may result either from climate extremes in single key countries or from simultaneous events in many regions. Trade and storage may act as alleviating mechanisms of the market uncertainty provoked by recurrent extremes (Chatzopoulos et al. 2021), as long as they are not disturbed by other (e.g. geopolitical) factors and events. Climate extremes also affect vulnerable and exposed communities, contributing to higher mobility and migration.

Interlinkages with other drivers

Climate change interacts with many other drivers of food security in often multiple and cascading ways. A wealth of profound assessments, e.g. from IPCC, FAO and other international organisations are available and frequently updated. Below main point from recent assessments and other studies are listed for some important interlinkages, acknowledging a much wider range of possible interactions that are not discussed.

Climate change and biodiversity: A FAO study on the role of Biodiversity for food and Agriculture (Bélanger and Pilling 2019)- concludes that the world's capacity to produce food is being undermined by humanity's failure to protect biodiversity. Over the last two decades, approximately 20% of the Earth's vegetated surface has become less productive. The study noted a "debilitating" loss of soil biodiversity, forests, grasslands, coral reefs, mangroves, seagrass beds and genetic diversity in crop and livestock species. IPCC26 AR6 WG2 (Pörtner et al. 2022) also notes the importance of safe-guarding biodiversity and ecosystems for climate resilient development, both for adaptation and mitigation for which effective and equitable conservation of approximately 30% to 50% of Earth's land, freshwater and ocean areas, including currently near-natural ecosystems would be needed. There is also evidence of climate change as an important driver of the decline of pollinators. The rate of change of the climate across the landscape is expected to exceed the maximum speed at which many pollinator groups are able to colonize new areas, and deteriorating the climatic suitability for pollination.(Dicks et al. 2021; Potts et al. 2016).

Climate change and financing of increasing climate resilience: There is a critical role for financial institutions in encouraging and facilitating access to capital for building greater resilience of agricultural systems, especially in emerging markets(IC 2021). Unavoidable, imminent effects of high-impact extreme weather events due to climate change will trigger shocks to the global food system and may lead to significant financial losses. It predicted that, as the impacts of climate change intensify beyond the next decade, yield losses will approach severe and widespread levels.

Climate change, energy, and food system emissions: Modern food production and processing are energy-intensive activities, with the industrial activities related to food systems requiring an estimated 26% of the EU's energy consumption. Modern agriculture is heavily dependent on fossil resources, although renewable energy technologies are mature to be implemented. Both direct energy use for crop management and indirect energy use for fertilisers, pesticides and machinery production and farm operation (e.g. irrigation) have contributed to the major increases in food production seen since the 1960s. Food accounts for some 25-30% of global greenhouse gas emissions (Crippa et al. 2021), with over 80 % of these emission related to the livestock sector. The average European per capita consumption of animal protein is now 50 % higher than in the early 1960s and double the global average.

A switch to more plant-based foods would not only enhance food security, but also present large benefits for climate mitigation while generating significant co-benefits in terms of human health (Mbow et al. 2019)

Decoupling further increases in productivity from fossil-fuel use and GHG emissions, through techno-logical and social/policy innovation, is a key challenge for sustainable food systems, and Horizon Europe provides funding for relevant projects. This includes projects that focus on specific agricultural practices, e.g. paludiculture as a way of producing biomass for different uses in the economy, while restoring the function of peatlands as a carbon sink. Agricultural R&I also helps strengthen the capacity of different actors in the sector (including farmers but also advisors, research stations) to adopt and further develop climate-smart technologies and practices, by supporting the creation and operation of demonstration and pilot networks across countries.

8.2. Environmental pollution

General context and what is at stake?

Air pollution is a driver of crop yield losses, via particular matter (aerosol) or ozone. Deposition of aerosol on crop leaves (e.g. dust) directly impacts plant productivity, or can cause the contamination by heavy metals(Mills, 2022a). However, under low-to-moderate pollution conditions aerosol can also have positive effects on crops by enhancing diffusive radiation used by plants to grow. Aerosols also modify weather and climate, indirectly affecting crop production. Overall impacts of aerosol on yields are mostly qualitatively known, and not included in crop loss assessment frameworks. There is robust evidence that ozone formed from precursors NOx, VOC and methane emissions is negatively impact-ing crop yields (Mills, 2022b). For example, annual wheat yield losses because of ozone air pollution are estimated at 5-10% of the EU overall production (Van Dingenen et al., 2009; Mills et al., 2018; Sampedro et al., 2020). Several pesticides used in the past are Persistent Organic Pollutants that are transported through the atmosphere and other environmental compartments and are now regulated under several international protocols (International Conventions, 2022)

The status of freshwater and marine ecosystems is, among others, affected by chemical pollutants and marine litter, including plastics. They affect the potential use of freshwater for drinking water and irrigation, damage aquatic ecosystems and ecosystem services such as to support biomass production (e.g., fish) and affect human health. Plastic and micro-plastic pollution of surface waters can impact the food webs of aquatic ecosystems (e.g. entanglement of large animals, gut obstruction by plastic objects, or bioaccumulation of microplastics). This can diminish the overall production of freshwater/marine ecosystems.

Water pollution can be further aggravated by climate change, when water availability in rivers and lakes is less, temperatures increase, and chemical and biological concentrations increase. Nutrients pollution and increasing temperatures have a strong impact on water quality, due to frequent algal and cyanobacterial blooms (eutrophication) and the release of toxins, both affecting food security. More-over, alterations of the natural status of aquatic ecosystems, such as eutrophication, can lead to a general decrease in biomass production, particularly at higher trophic levels (e.g., fish, shellfish, etc.). Impacts can be exacerbated by climate change.

Soil pollution. Understanding pollution of soil also needs to be improved. Potentially harmful sub-stances are deliberately applied to the soil, either to combat pests (e.g. biocides) or as part of waste-management practices (e.g. unintentional releases from landfills). Some organic waste streams enrich the soil with nutrients and organic matter (e.g. manure, sewage sludge). Thirdly, while soils (and the biological communities they sustain) can filter and transform pollutants, they can also accumulate them and become a potential source of pollution for other media. Also, soil pollution caused by overdosed application of mineral fertilisers or by the content of heavy metal in fertilisers needs to be considered.

Current assessment – 2022-24

Regarding air pollution, crop losses (Van Dingenen et al., 2018b) have been estimated in several assessments for a variety of scenarios. Current crop losses estimated for the year 2020 for EU27+UK amount to 7.3 Mt (aggregated relative yield loss of 4.5%) with wheat accounting for 76% of total crop loss, maize (21%), soybean (2%) and rice (1%). A study applying a different methodology(Mills et al., 2018) reports for 2010 a crop production loss of 20 Mt (5 – 10%) across Eu-rope for the same four crops. The EEA (Schucht et al., 2021) estimated the total wheat loss due to ozone damage in 2019 to almost 2 million tonnes (valued at EUR 350 million) for France alone, and 1.6 million tonnes or EUR 280 million for Germany, the two EU Member States with highest total monetary losses. The highest percentage of crop losses were found to be for Greece, Portugal, Cyprus and Czechia, all with 8-9 % of the wheat crop lost because of ozone damage.

Regarding water quality, agriculture is the dominant contributor to nitrogen discharge, and in many EU countries the use of animal manure and synthetic fertilisers has been increasing. Nitrate concentrations in surface waters and groundwater are still high and extensive eutrophication has been reported throughout Europe estimates. Improved manure management in anaerobic digestion to produce biogas for biomethane and digestate would reduce nitrogen discharge while adding to the EU energy resilience from natural gas imports.

Forward looking – 2030

Modelling shows that –- under implemented current legislation the EU27+UK yield losses remain at 4.5%, while ambitious air quality legislation (MFR scenario IIASA) would reduce this to 2.4%.

The Zero Pollution Action Plan acknowledges the urgency of tackling pollution and the synergy with other European Green Deal initiatives on climate change, biodiversity and a circular economy. The Zero Pollution Outlook Report assesses the evolution of air, water and soil pollution in the light of the initiatives taken under the European Green Deal including, where possible, the feasibility of reaching 2030 targets of the Zero Pollution Action Plan. It will provide a comprehensive overview of various sources of pollution and include modelling exercises carried out in the context of the 3rd Clean Air Out-look and the JRC Blue2 modelling initiative.

International dimension

Pollution is a global and transboundary challenge with impacts of food production and food quality worldwide. Examples include pollution in marine basins shared by multiple countries, or air pollution in neighbouring regions and countries. Worldwide regions affected most by ozone pollution are India and China, characterized by high levels of pollution and (semi-)tropical conditions conductive to high impacts (Mills et al., 2018). Global yield loss attributable to ozone damage for the year 2010-2012 amount to 7.1 % for wheat and 12.4 % for soy bean, and around 6% for maize and 4 % rice, corresponding to a cumulative loss of about 227 Mt for the four crops(Mills et al., 2018). Using a different set of impact metrics, JRC modelling (Van Dingenen et al., 2018b) estimates a global yield loss of 93.5 Mt (5.4%) in 2010 for these four crops.

In addition to air pollution mitigation, also global methane mitigation can play an important role in sustainably improving global agricultural production. Stringent methane mitigation, following a sustainability pathway, could reduce ozone induced crop economic losses in Europe by 2 to 7% in 2030 relative to 2010 (1 to 4% globally). On the other hand, a high methane emission pathway would add 8 to 15% crop economic losses in 2030 relative to 2010 in Europe, and 4 to 8% globally (Van Dingenen et al., 2018a). The new Commission's proposal for the revision of the Industrial Emissions Directive aims to, inter alia, reduce methane emissions from livestock. With the proposed threshold of 150 livestock units, the proposal includes the 13% largest livestock farms, responsible for 43% of methane emissions.

Agricultural activities (livestock and waste management, manure and mineral fertiliser, crop residue burning, bare soils, and mechanical processing) are globally major contributors to air pollution, representing 58 % of primary PM2.5 emissions, and 72 % of NH3 emissions (Balasubramanian et al., 2021; Crippa et al., 2022).

The European Commission has a long-standing collaboration with the UNECE Convention on Long-range transport of air pollution (CLTRAP), and signed up to several of its protocols. There is a scientific collaboration of the JRC with the Arctic Assessment and Monitoring Programme (AMAP).

To address the fundamental need for international collaboration, when fighting global pollution, the European Commission and UN Environment have agreed to work together at the global level to urgently reduce pollution in an integrated manner. Both partners are also paying increasing attention to nature protection and restoration as one of the solutions to tackle the triple planetary crisis of pollution, climate change and biodiversity.

Interlinkages with other drivers

Environmental pollution is linked to many other drivers. Environmental degradation can be enhanced by climate change and, in turn, could affect negatively biodiversity and soil health, and play an important role in the emergence and spread of plant pests and animal diseases. Interactions of air pollution and climate change can affect agricultural yield, hence impacting farm income and food prices. Pollution is closely related to food waste, fertiliser use, intensity of production etc.

8.3. Soil health

General context and what is at stake?

About 95% of food comes from terrestrial sources and depends on healthy soils, able to provide sufficient, safe and nutritious food and a range of vital ecosystems services, such as clean water, habitats for biodiversity, nutrient cycling and carbon storage. Soil is a fragile and non-renewable resource that is threatened all over Europe and globally. The main drivers of soil degradation in Europe are human activities, such as intensive agriculture, drainage, and the spread of persistent pollutants. Land take and soil sealing are also leading to an irreversible loss of the most fertile soils due to urbanisation and infrastructure substantially affecting agricultural production. Safeguarding healthy soils is ever more important given the threat to global food security associated with Russia's unprovoked invasion of the Ukraine.

Soils are the basis for agricultural food production and act as buffers against climate change risks, such as floods and droughts. Unhealthy soils will produce less than its actual potential and will be less resilient to extreme weather events, leading to increased impacts of flooding and droughts. Once the soil is degraded, the food production is at risk and it will take time and effort to revert the soil to a healthy condition and its full production capacity. For some soil degradation, such as loss of soil carbon, erosion, compaction, or soil sealing, it may take decades or even hundreds of years to restore the soil properties and optimising the delivery of essential ecosystem services. Indirect impacts, include pollution of surface waters by fertilisers and chemical pesticides, and desertification in arid and semi-arid regions. Soil degradation reduces biodiversity, efficiency in nutrient cycling and productivity, which in turn increases food insecurity and plant, animal and human diseases.

Degraded soils do not only lose their capacity to act as carbon stores, but also the capacity to filter and store contaminants, thereby releasing pollutants which may end up in the groundwater or enter the food chain. Some soil contaminants such as cadmium or microplastics enter the food chain directly being absorbed by the plants. As such, degraded soils also pose a threat to food safety.

Soil conservation measures (e.g. increased vegetation cover throughout the year, reduced tillage) and crop management are key measures to restore the soil fertility on arable lands. Crop management includes crop rotation, which improves soil structure and water retention capacity, increases soil organic content and soil biodiversity. This leads to enhanced natural weed and other pest control, and higher yields, in particular in combination with intercropping.

Current assessment – 2022-24

About 60-70% of EU's agricultural soils are currently either losing organic carbon, receiving more nutrients than they need (affecting also water resources and natural habitats), eroding or compacting, suffering secondary salinization, or some combination thereof (Veerman et al., 2020).

Natural soils (i.e., without intensive management regimes) make up 52% of the soil in the EU. There are potentially 2.8 million potentially contaminated sites (Paya Perez et al., 2018), 83% of agricultural soils with residual chemical pesticides (JRC work on LUCAS 2018 in progress); agricultural soils with nutrient inputs at levels risking eutrophication of soils; cropland soils losing carbon at a rate of 0.5% per year; 24% of land with unsustainable water erosion rates (Panagos et al., 2020); 23% of land with high density subsoil indicating compaction (Montanarella et al., 2021); 25% of land at high or very high risk of desertification in Southern, Central and Eastern Europe (Prăvălie et al., 2017).

The costs associated with soil degradation in the EU exceed EUR 50 billion per year (European Commission, 2021) but has enormous uncertainties. For six land degradation processes (water erosion, loss of Phosphorus, loss of carbon due to soil erosion and land use change, sediments removal and management of contaminated sites), the JRC estimated a cost of 15 billion per year. The 12 million hectares of agricultural areas in the EU that suffer from severe water erosion are estimated to lose around 0.43% of their crop productivity annually (annual cost of 1.25 billion Euros) (Panagos et al., 2018).

A review of the current evidence of the state of EU soils by the Mission Board "A Soil Deal for Europe" and the JRC EU Soil Observatory concluded that the management practices result in approximately 60-70% of EU soils being unhealthy (Veerman et al., 2020) with a further uncertain percentage unhealthy due to poorly quantified pollution issues or disposed unnecessarily as waste. A radical change in current land management practices is both feasible and necessary. Soils could also benefit from improvements to indirect drivers of change, such as reductions in water pollution, and carbon and non-carbon GHG emissions into the atmosphere.

Apart from unsustainable farming practices, such as intensive soil tillage, excessive fertilisations and, successions of monoculture, the main drivers of soil degradation in Europe are soil contamination and soil sealing (land take) by infrastructure and housing. Especially severe is the irreversible loss of the most fertile soils due to urbanisation and infrastructure substantially affecting agricultural production (Gardi et al., 2015). As an example, the potential of agricultural production capacity has been reduced by 0.81% in the period 1990-2006 due to soil sealing alone.

Additional threats to soil health concern soil erosion, especially in EU agricultural lands. A quarter of the EU's land has erosion rates higher than the threshold of 2 t $ha^{-1}yr^{-1}$, implying a substantial loss on ecosystems services provided by soil. Among those are the losses of phosphorous by water erosion that globally amount to 50% total phosphorous losses in agriculture, on which the food production is directly dependant. So far, in Europe the net losses are much smaller due to higher fertiliser inputs and less erosion in the global context. Some regions have even built up a significant legacy of phosphorus in soils due to intensive fertilisation and livestock farming over many years. However, the risk of phosphorous net losses might increase in some regions with reduction in the use of fertilisers and increased soil erosion of 13% and 23 % in EU until 2050 due to climate change effects. The soil losses are even higher when other processes are also accounted (e.g. wind erosion, tillage, crop harvesting) (Borrelli et al., 2022).

No-tillage leads to a significant restoration of soil quality, even more effective if this is combined with organic fertilisation (Sanden et al., 2018; Badagliacca et al., 2020). When no-tillage is combined with cover crops, it can maintain crop yield and reduce costs while enhancing soil fertility (Triplett et al., 2008; Jacobs et al., 2022).

Forward looking – 2030

The underlying drivers of soil degradation are not projected to change favourably, so the functionality of soils is under even more pressure. Harmonised, representative soil monitoring across Europe is needed to develop early warnings of exceedances of critical thresholds and to guide the restoration of soil health and sustainable soil management. According to latest climate change projections, the rainfall intensification (and the consequent the soil erosion) will increase by 13-23% in the EU until 2050 (Panagos et al., 2021). On a global scale this increase is even more alarming as the projections refer to an increase in the range of 30-66% by 2070 (Borrelli et al., 2020). Also, the increase of temperature will further contribute to loss of soil organic carbon and less fertility from soils (Lugato et al., 2018).

It is estimated that, globally, 33% of soils are presently moderately to highly degraded due to erosion, salinization, acidification, contamination, or compaction (FAO & ITPS, 2015) and that 52% of agricultural land is already moderately or severely affected by soil degradation(ELD, 2015).

Each year about 10 million ha of cropland is lost due to soil erosion, thus reducing the cropland available for food production (Pimentel et al., 2006). In addition, the trend of current global soil loss is emerging as we estimated an increase of soil erosion by 2% in period 2001-2012 due to land use change (Borrelli et al., 2017).

Salinization leads to a severe damage of a further 10 million ha/y (Pimentel and Wilson, 2004) which diminish further food security. Farming systems that use integrated management with rotation and organic fertilisers[9] can maintain soil health (Fließbach et al., 2007). Crops require 16 essential chemical elements for a fully and balanced development, and deficiency in anyone restricts plant growth and reduces crop yields affecting largely on food security. (Marschner, 2012). On acid soil, which occupies about 40% of the world's agricultural land, toxic concentrations of manganese and aluminium limit crop production, whereas on sodic and saline soils (5–15% of agricultural land) too much sodium, boron and chloride frequently reduce crop production. Soil degradation–including the depletion of nutrients and organic matter, declines in cation exchange capacity, structure and water-holding capacity, increases in leaching, acidification, compaction, erosion, salinization, sodification and desertification–resulting from man-induced processes is widespread on land used for agriculture. These adverse and cumulative changes reduce the soil's capacity to support crop growth and animals and thereby impair food security.

The EU Soil Observatory (EUSO) was launched in 2020 to generate and disseminate policy-relevant and harmonized EU–wide soil data and indicators in support of the soil perspectives of the European Green Deal. Among others, the EUSO will establish a comprehensive dashboard containing indicators that present data on soil-related issues within and, in some cases, outside of the EU. Examples of indicators include soil erosion, soil carbon, pollutants, soil biodiversity and soil nutrients (phosphorus, nitrogen, potassium) with relevance to the EU Soil Strategy for 2030, the upcoming Soil Health Law, the Common Agricultural Policy (CAP), Zero Pollution Action Plan and Sustainable Development Goals (SDGs).

Soil health is also a pressing global issue that sits at the heart of three UN conventions (UNCBD, UNCCD, IPBES and UNFCCC) and of the SDGs. Therefore, international R&I cooperation on soil health will also be fostered in the context of the Soil Mission. A first international cooperation activity launched in the context of the Mission is the funding of the ORCaSa (Operationalising International Research Cooperation on Soil carbon) Coordination and Support action, which will be in charge of setting up an International Research Consortium on (agricultural) soil carbon aiming at achieving coordination of R&I at the global level in the area of soil and carbon.

International dimension

The soil degradation is assumed to cost the world USD 400 billion per year. Accordingly, it is predicted that land degradation over the next 25 years could potentially reduce global food productivity by 12% and increasing food prices by 30% (Kopittke et al., 2019; ELD, 2015).

On a global scale, soil erosion may decrease food production by 33.7 million tonnes with accompanying rises in food world prices of 0.4-3.5% (Sartori et al., 2019). Highest productivity losses are observed where the highest erosion rates (mean erosion in arable lands > 11 t ha^{-1} yr^{-1}) occur in countries with high share of agricultural land (Fig 1). In addition, this soil threat puts pressures to use more marginal land increasing the abstracted water volumes upwards by 48 billion m^3.

Soil phosphorus (P) loss from agricultural systems will limit food and feed production in the future. Globally, agricultural soils will be depleted by between 4–19 kg ha^{-1} yr^{-1} of Phosphorus due to erosion by water with Africa and South America being the most affected continents (Alewell et al., 2020).

The climate change will increase rainfall intensity (erosivity) globally at the range of 26%-35% accelerating faster the land degradation processes mostly in the cold and arid zones. At global scale the climate change impact combined with land use changes will further increase soil loss in the range of 30-66% by 2070 compared to 2015 (Borrelli et al., 2020).

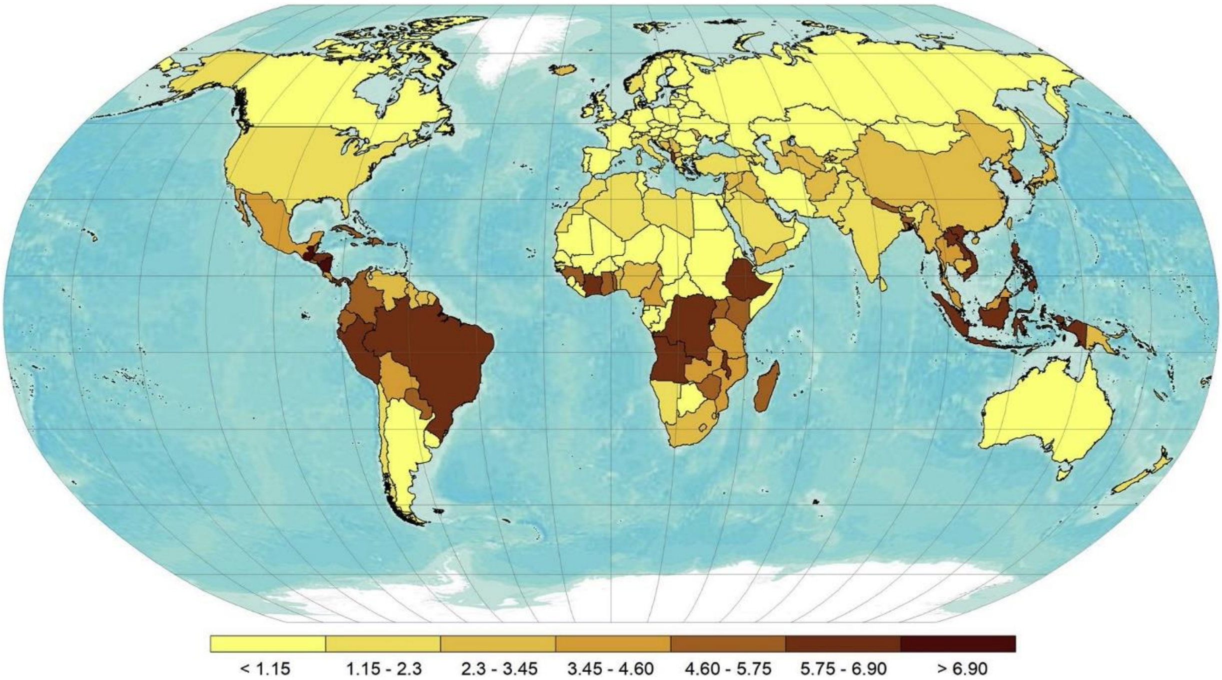


Figure 1: Estimated annual absolute land productivity losses (%) due to soil erosion

Interlinkages with other drivers

Soil health is directly related to biodiversity, land management, nutrient management, fertilisers, pollution, climate change and livestock. For example, intensive land management practices (tillage, overgrazing, mono-cropping, excess of fertilization and pesticides, etc) will further degrade agricultural soils due to soil loss, carbon loss and diffuse contamination. Healthy soils are the basis for healthy food production as soil is responsible for the production of 95% of our food (FAO, 2022). Therefore, an un-health soil has negative effects in above ground biodiversity, food safety and habitat loss.

Important land use change such as conversion of grasslands to cropland will contribute to carbon losses and erosion risk. In addition, climate change and the consequential increase in rainfall intensity (erosivity) will result in higher soil and nutrient losses. The increase of temperature will contribute to soil organic carbon loss (less fertility), peatlands degradation and CO_2 release to the atmosphere. The consumer demands and change of diets which result in livestock increase may cause overgrazing and lead to excessive emissions of nutrients from intensive livestock operations into the natural environment.

8.4. Pests and diseases

General context and what is at stake?

Plant pests and diseases can broadly impact food production and food security. The Food and Agriculture Organization (FAO) estimates that plant pests cost approximately USD 220 billion annually and that up to 40 % of food crops are lost due to plant pests and diseases globally every year (Savary et al. 2019; Renault et al. 2022). Hence, improving phytosanitary conditions could significantly contribute to safeguarding food security. Globalisation, international travel, and trade can unintentionally rapidly spread pests and diseases worldwide, causing significant damage to crops, native plants, and the environment (Hulme 2021). Globally, the societal costs of invasive species between 1970 and 2017 are estimated at a minimum of $1.3 trillion (Diagne et al 2021). Over 11 000 invasive species have already spread into Europe with the average annual rate of establishment progressively increasing over the last century (Hulme et al. 2009). Estimates by the European Commission suggest that these species already cost taxpayers 12.5 billion Euro annually. ([52]) Considering that for almost 90 percent of invasive species information on impact in Europe is missing, this arguably represents a rather conservative estimate (Vila et al. 2010).

In addition, keeping healthy crops has become more challenging due to climate change, with associated changes in pest-habitats (Lawton et al. 2022). The International Plant Protection Convention (IPPC) published a new review where scientific evidence strongly indicating that rising temperatures likely will influence pest movement and establishment. ([53]) An increased presence of plant pests and occurrence of outbreaks is a pressure that reduces yields of affected crops leading to overall lower production. Global yield losses of wheat, rice and maize are projected to increase by 10-25% per degree of global mean surface warming due to insect pests.

Besides the pesticides' positive function as damage control agents, their use also leads to unintended consequences. The consequences for the environment and human health from misuse of these chemicals are of societal concern (Kohler et al. 2013, Edlinger et al. 2022).Pesticide residues are found in soils, surface water, groundwater, non-target plants, food and feed, animals and humans (Aktar et al. 2009, Popp et al. 2013, Sharma et al. 2019). Pesticides can remain for years in the environment and accumulate in soils and water, but also in humans, albeit that in Europe levels of pesticide residues in food products beyond the legal limits are rare.

For Europe, the maximum potential impact of 28 union quarantine pests in terms of the maximum production lost has been quantified. The cumulative impact of these pests only may reach over EUR 25 billion for annual crops, representing around 20% of the total EU production value . In terms of relative production a maximum of 69% of production would be at risk (olive production due to *Xylella fastidiosa*). The outbreak of these pests would put at risk a total value of EUR 22 billion of agricultural exports, with a maximum of EUR 5 billion for wheat if there was an outbreak of *Tilletia indica*. This would also mean -3.2% of current calories supply, - 2.2% of protein supply and - 1.0% fat supply. The analysis also focuses on non-economic impacts such as reduced food availability (a maximum of 3% of total caloric intake) or impact on trees in streets and city parks.

The review of the data for plant pest control activities undertaken with the support of the Union budget shows that over EUR 20 million were invested in 2018 (latest available figure). The trend is increasing and most of the expenditure is undertaken in France, Spain, and Italy with a

([52]) https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52008DC0789&from=EN

([53]) https://www.fao.org/3/cb7056en/cb7056en.pdf focus on visual examination and testing. There seems to be a reasonable correlation between the surveillance efforts and the expected impacts.

Animal diseases threaten the health of millions of livestock on a daily basis ([54]). With continuing population growth and rising demand for food diversification, livestock and aquaculture are factors relevant for the improvement of food and nutrition security, health, and livelihoods. Across the world, livestock production and aquaculture are in certain instances important elements for human nutrition and health. Animals can play a critical role in society, providing income and food, but also clothing, building materials, fertiliser and draught power, especially in the most vulnerable countries. Production animals constitute 40% of the value of global agriculture. Globally, 1.3 billion people directly depend on food animals for their living. Of these, 600 million are smallholder farmers in some of the world's poorest countries (Thornton et al.). However, the presence of endemic and emerging diseases can negatively impact production animals, jeopardising their contributions (J. Rushton et al., 2021).

Some crises, such as the African swine fever (ASF) worldwide requires global action and effective collaboration and communication as it severely impacted global pork production. (Chair´s Conclusions from the high-level international conference "The Future of global pork production under the threat of African swine fever" Berlin (Germany), 17 January 2020).

At the same time, excessive use of antimicrobials to treat animals poses increasing risks: antimicrobial resistance is a well-documented major health threat across the globe that has been given high priority by the WHO and the European Commission. Antimicrobials are widely used, sometimes misused, in veterinary medicine, often as preventives. Antimicrobial resistance is growing in domesticated animals, especially in industrialized agriculture, and can increase risks of disease emergence both in livestock and in humans ([55]) as resistant bacteria can be transmitted from wild and domestic food animals to humans via the food chain, environment, or direct interaction with animals ([56]). This may lead to the emergence of infections that are challenging to manage ([57]) and it is estimated that antimicrobial resistance causes 700,000 deaths annually ([58])..

The Animal Health Law (Regulation (EU) 2016/429) lays down rules for the prevention and control of animal diseases which are transmissible to animals or to humans. In laying down those animal health rules it takes into account the interdependencies between animal health and human health, the environment, food and feed safety, animal welfare, food security, economic, social and cultural aspects. The importance of applying a One Health approach is further

([54]) Animal Diseases and their Threat to Food and Food Security - Center for Infrastructure Protection & Homeland Security (gmu.edu)

([55]) United Nations Environment Programme and International Livestock Research Institute (2020). Preventing the Next Pandemic: Zoonotic diseases and how to break the chain of transmission. Nairobi, Kenya.

([56]) Iramiot, J.S., Kajumbula, H., Bazira, J. *et al.* Antimicrobial resistance at the human–animal interface in the Pastoralist Communities of Kasese District, South Western Uganda. *Sci Rep* **10**, 14737 (2020). https://doi.org/10.1038/s41598-020-70517-w

([57]) Butaye, P. A, Maria, A. A., & Threlfall, J. Introduction to antimicrobial-resistant foodborne pathogens. In *Antimicrobial Resistance and Food Safety Cambridge*, MA, USA 1–8. 2015.

([58]) O'Neill. Antimicrobial resistance: Tackling a crisis for the health and wealth of nations. Rev. Antimicrob Resist. 2015.

underlined by the fact that the majority of human infectious diseases (58-65%), is zoonotic ([59]), meaning that the responsible pathogens are derived from animals and transmitted to humans. Nearly all these zoonotic pathogens arise from warm-blooded animals, predominantly mammals and in some cases birds (ibid). Most animal-to-human transmissions occur where contact between humans and animals is close and/or frequent, including with livestock ([60])..

Current assessment – 2022-24

For many pests, the fertiliser use and intensity of production are strongly related to pest pressure with complex interdependencies. A higher fertiliser uses in some crops results in a greening of the plant that can attract pests, in turn demanding higher pesticide use. Conversely, nutrient deficiencies lower the general resilience of the plant which may affect the impacts under varying levels of pest or disease pressure. Land management and landscape composition is closely related to pest spread and therefore also the impact (Topping et al. 2015, Epanchin-Niell et al. 2010, 2012).

Since the green revolution, the agricultural system has moved to an approach to manage pest based on the use of chemical pesticides. The standardization of farming systems with less biodiversity at farm level (monocropping, few rotations) and landscape level (larger plots, removal of hedges, etc.) increase the risk of pests, leads to the development of pests' resistance to chemicals and finally is leading to a constant increase in pesticides use, often described as the *pesticide treadmill* (Hedlund et al. 2020). Even when farmers apply a multitude of agronomic strategies to minimize pest and disease impacts in their fields, the use of pesticides remains a last resort option (Sharma et al. 2019). The consequences for the environment and human health from use and misuse of these chemicals are of societal concern (Kohler & Triebskorn 2013, Edlinger et al. 2022). Pesticide residues are found in soils, surface water, groundwater, non-target plants, food and feed, animals and humans (Aktar et al. 2009, Popp et al. 2013); albeit that the high food safety standards in Europe generally lead to a small percentage of products which are contaminated with pesticides beyond the legal limits. ([61]) Focused production using a limited diversity of crops within a monoculture setting may also increase the risk and severity of pest impacts (Andow 1983). The Sustainable Use Directive fosters better management approaches via Integrated Pest Management principles.

Forward looking – 2030

The severity of the impacts described above will change with new trade and climate patterns and availability of pest control tools including chemical or biological plant protection products or agricultural practices. Most studies highlight that the impact will be on increased risk of losses, thus adding pressure to food security concerns.

While the severity of the impacts is expected to increase, also the availability of alternative solutions to widespread chemical plant protection products is expected to widen. These

([59]) European Group on Ethics in Science and New Technologies, Group of Chief Scientific Advisors, *Improving pandemic preparedness and management : lessons learned and ways forward : independent expert report*, Publications Office, 2020, **https://data.europa.eu/doi/10.2777/370440**

([60]) United Nations Environment Programme and International Livestock Research Institute (2020). Preventing the Next Pandemic: Zoonotic diseases and how to break the chain of transmission. Nairobi, Kenya

([61])https://www.efsa.europa.eu/en/news/pesticides-food-latest-report-published#:~:text=68.5%25%20(8%2C278%20samples)%20were,0.9%25)%20were%20non%2Dcompliant.

alternatives are not only expected to substitute toxic chemical plant protection products by less toxic and biological alternatives. In view of the increasing rate of introduction and the simultaneous removal of high-risk pesticides, efforts to speed up the development of alternative solutions are called for. For example, New Genomic Techniques may deliver important advances through varieties with durable biotic resistances, at a faster pace. A systemic change on how pests are managed can be achieved with widespread implementation of Integrated Pest Management and intensity of use can be reduced with improved prediction of pest risk, early detection, and targeted application of plant protection products. A broadening of the perspectives on plant health through a holistic view, i.e., the "One Health" approach, will likely be conducive toward positive changes in crop-, animal-, human-, and ecosystem-health.

International dimension

Pests do not respect borders. The control of pest invasions is a so-called 'weakest-link public good' (Perrings et al 2010), which implies that benefits are neither *rival* nor *exclusive,* while the outcome is largely determined by the least effective decision-making unit. In weakest-link public goods, decision-making units' best interest is to cooperate with the weaker links to incentivize their private control efforts (Fenichel et al 2014). As mentioned, increased global trade, climate change and global environmental degradation raises the risk of pests spreading to areas where they are not present and the severity of their potential impact. Europe is one of the centres for international trade in general (De Benedictis & Tajoli 2011), and for plant products in particular (Maxwell et al. 2014). As invasive pests are externalities of international trade (Perrings et al. 2010, Hulme2021), Europe is greatly at risk of suffering unintended costs from trade through spread of hazardous species.

Global initiatives such as the International Plant Protection Convention (IPPC) try to reduce this by developing harmonized control and rapid alert systems. The EU's Plant Health Legislation has also introduced pest categorization, limits to trade of high-risk plants and traceability via Phytosanitary Certificates (for extra-EU trade) and Plant Passports (for intra-EU trade). However, higher phytosanitary standards may pose challenges to less developed regions, which in turn risk getting excluded from international trade. International collaborations are therefore essential to safeguard that the management of transboundary diseases does not affect regional development goals.

Some plant pests are of particular importance for low-income countries, e.g. in Sub-Saharan African and South Asia. International cooperation via the CGIAR is promoting the development of pest resistant traits via New Genomic Techniques for pests (e.g. Maize resistance to Lethal Necrosis – Boddupalli et al. 2020). In view of more holistic management strategies, the EU is supporting CGIAR and the DeSIRA initiative through "One Health" approaches.

Interlinkage with other drivers

This driver is **closely related to many of the other drivers**, and in a way is driven by the combination of many of them. Focusing on how other drivers can affect plant pests, important interlinkages can be mentioned for four of the other drivers. First, climate change directly affects the risk of new plant pest outbreaks through shifts in pest habitats increasing the suitability of the EU to the establishment and outbreaks of pests (Lawton et al. 2022, Skendžić et al. 2021). Biodiversity loss and environmental pollution and degradation might increase the potential impact of the outbreaks (see also Pesticide driver). Invasive species, including in the maritime environment, are among the biggest contributors to global biodiversity loss (Mollot et al. 2017). Conversely, strategies aimed at increasing biodiversity and soil health can be used in the context of integrated pest management to enhance the resilience of agro-ecosystems while reducing their vulnerability to outbreaks of pests and diseases. Investments on research and development are also central to find solutions for future pest management, such as (but not limited to) the replacement of chemical plant protection products by less toxic or biological products and through a diversification of management tools. Plant pests and animal diseases are linked to various socio-economic drivers. In particular, they can have negative impacts on farm income and food prices, and increase food losses and waste.

8.5. Biodiversity

General context and what is at stake?

Biodiversity is crucial for safeguarding EU and global food security (FAO, 2019). It supplies many vital ecosystem services, such as healthy soils, pollinating plants, controlling pests, and provides habitat for wildlife, including for fish and other species that are vital to food production and primary producers' livelihoods. **Biodiversity makes food production systems and livelihoods more resilient** to shocks and stress (Dardonville et al., 2022), including those caused by climate change.

Biodiversity loss threatens food systems, putting food security and nutrition at risk. Over a half of global GDP depends on nature and the services it provides, and more than 75% of global food crop types rely on animal pollination (Klein et al. 2007). In the EU alone, around 84% of crop species and 78% of wild flower species depend, at least in part, on animal pollination. Pollinating insects especially wild pollinators (Weekers et al., 2022), provide vital ecosystem services to crops and wild plants. Despite their importance, recent scientific evidence has shown clear declines in both wild and domesticated pollinators in several regions of the world (Potts et al. 2010, Powney et al. 2019). The decline in pollinators can result in loss of pollination services that could significantly affect the maintenance of wild plant diversity, wider ecosystem stability, crop production, food security, and human welfare.

A recent study conservatively estimated the global value of animal pollination to crop production at €158–412 billion per year (Stout et al., 2019). Collectively, pollinators provide more than EUR 14 billion per year to the market value of European crops (IPBES 2016) and more than EUR 1500/ha. At global level, pollinators are required for reproduction of almost 90% of angiosperms and therefore are a limiting factor of most plant communities and vegetation types. Pollinators improve production of 70% of the globally most important crop species and – although the main cereal staple food are self-pollinated - influence 35% of global human food supply (Tscharntke et al., 2012 and references therein).

Pests and diseases are part of the agroecosystem. Among the strategies to minimise pest and disease impacts, the contribution to pest control of natural enemies of crop pests has been estimated to account for at least 50% of pest control occurring in crop fields (Pimentel, 2005). Results of recent projects (i.e.: H2020 Diverfarming) also demonstrate the influence of crop rotation, crops combination and varietal selection to reduce pest impacts.

As such, pollinators' decline is a major threat to food production and food security. While studies quantifying the overall value of natural pest control by beneficial insects at the EU scale are missing, individual studies on single crops/region can be illustrative of the importance of this service. The economic value provided by natural pest control on wheat in South-East England alone has been estimated to be around £2.3 M over a 5 years period (Zhang et al., 2018), while Daniels et al (2017) calculated that the loss of pests' natural enemies could decrease net pear farm income between 88.86 €/ha and 2186.5 €/ha.

In relation to food security, the loss of functional biodiversity directly translates into the decrease of the aforementioned ecosystem services (Hooper et al., 2012, Grab et al., 2019; Greenop et al., 2021). In turn, this has led to exploring ways to substitute or integrate such services with anthropogenic solutions provided by markets and technology. For example, the loss of pollinators and the pollination service they provide could be replaced by managed pollinators or artificial pollination; the loss of predators of pests and the natural pest control service they provide could be substituted with the use of chemical pesticides; and the loss of soil biodiversity and the nutrient cycling service could be substituted with the use of mineral fertilisers. These substitutive actions, besides being costly, may not provide outcomes comparable to the ones provided by natural processes, such as the improvement of fruit quality and the economic value provided by insect pollination enhances (Garratt et al., 2014).

Agricultural biodiversity is not just a source of food for humans, but it is also the pillar of a multitude of ecosystem services crucial for food security, such as soil and water conservation, the maintenance of soil fertility, and pollination. Moreover, the dependency on mineral fertilisers and chemical pesticides can only be substantially reduced if the ecosystem functions providing the corresponding services are optimized. In addition, a wide and varied genetic diversity of agricultural biodiversity improves the resilience of agroecosystems to increasing extremes (frost, drought, diseases, pests, etc.) caused by climate change.

Evidence shows that restoring agroecosystems has positive impacts on food productivity and food security through higher yields, improved nutritional content and stronger resilience and stability against climate and socio-economic disturbances in the long term. More biodiverse and resilient agricultural ecosystems also reduce dependence on imports. The restoration of nature acts as an insurance policy for the EU’s long-term sustainability and resilience against all these challenges. A review of the scientific evidence conducted by the JRC shows that ecosystem restoration and sustainable farming practices have a positive impact on food productivity and resilience (Liquete et al., 2022).

In the marine environment, human-induced stressors continue to erode biodiversity, for example through the unsustainable influx of pollutants, organic matter and contaminants (including micro- and macro-plastics), fishing activities that adversely affect seabed habitats. Ultimately, these stressors affect marine life and decrease its resilience to climate change. Through seafood, stressors such as contaminants also pose a risk to human health. Healthy marine food webs require healthy marine ecosystems. Sheltering part of the marine environment from direct human adverse impact, for example through setting up Marine protected areas (MPA), is an effective way of enhancing marine biodiversity resilience and of contributing to attenuating climate change through carbon capture in primary producers’ biomass and sediments. Further, the spill-over effect of protected areas provides benefits to the fisheries industry and contributes to food security, availability and affordability.

Current assessment – 2022-24

In October 2020, the Commission published the results of the EU-wide ecosystem assessment, which also included insects-pollination services in the EU (Maes et al., 2020). The results showed that 50% of the land cultivated with pollinator-dependent crops faces a pollination deficit. One of the best ways to address this pollination deficit would be through ecosystem restoration, supported by agricultural policy.

There is evidence that inclusion of landscape features in farms and increasing the landscape complexity has positive effects on pest control around arable land and pollination (emphasized by a floral abundance). Martin et al. (2019) found a 1.4-fold increase in pest control and a 1.7-fold increase in pollination observed in landscapes with high edge density. Albrecht et al. (2020) estimated that flower strips and hedgerows enhance pest control by 16%. In some cases, these positive effects can translate into higher yields (Mei et al., 2021).

The ecological contribution to the growth of cultivated crops should be disentangled from the total yield production, which is made possible by substantial human inputs invested for crop production (i.e., planting, irrigation, labour, and chemical inputs). At the EU level, ecosystem contribution to crop provision is about 21% of the total yield value. The rest is due to human inputs. The value of crop provision as an ecosystem service represented about EUR 20.6 billion in 2012, including the value of soil retention service. This was an increase of 32% since 2000. If soil retention is excluded, the value decreases to EUR 11.4 billion, representing 10% of the total yield value (as opposed to 21%) (Vallecillo et al. 2019).

In the marine environment, the need to safeguard biodiversity is enshrined in major regulations such as the Common Fisheries Policy (CFP; Regulation No 1380/2013), which suggests the implementation of an Ecosystem-Based Approach to Fisheries Management, and the Marine Strategy Framework Directive (MSFD; Directive 2008/56/EC), where maintaining biological diversity consists of the first Descriptor (D1) of Good Environmental Status. Both the exploitation and state of EU commercial stocks have exhibited substantial improvements over the past two decades in the NE Atlantic, but this is not the case in the Mediterranean where only small improvements have yet been achieved (STECF, 2022). Moreover, restoration of marine ecosystem through properly enforced marine protected areas has a positive spillover effect in the surrounding fisheries, and this effect can increase gradually over the coming decades. The spillover effect is of major importance around no-take zones, with examples of catches raised 2 ½ fold in only a four-year period and with beneficial side effects in fishers' income, tourism, social well-being, and the regeneration of distant fisheries. (Liquete et al., 2022).

Forward looking – 2030

A complete pollinator loss would translate into a production deficit over current consumption levels of -12% for fruits and - 6% for vegetables (Gallai et al. 2009). The currently ongoing EU Pollinator Initiative aims at improving our understanding of the status and trends of pollinator species. The Initiative sets long-term objectives for 2030 which dealt with generating actionable knowledge about the problem, tackling the problem's main known causes, fostering stakeholder collaboration and engaging society at large.

Food productivity can be enhanced by pollinators' abundance and diversity especially in cases where pollen is a limiting factor. Some articles have reported increases in crop yield following the introduction of wildflower strips and field margins in farmlands (e.g., +42% in avocado, +12% in blueberry) (Lechenet et al., 2017). Maintaining high floral diversity and perennial floral plantings is essential for the effectiveness of these measures. At a larger scale, agricultural diversification has also proven to enhance biodiversity, pollination and pest control without compromising crop yields (Tamburini et al.2020).

International dimension

In its statement ([62]) at the UN Food Systems Summit 2021, the EU declares that "Food production and consumption are major drivers of the climate crisis and looming ecocide. And yet, agriculture and farmers are the first to suffer the consequences if we fail", highlighting the

([62]) https://www.un.org/sites/un2.un.org/files/2021/10/FSS_statement_EU.pdf link between biodiversity and food production. An even more direct link between biodiversity loss and global food security is presented in one of the key messages in the summary for policymakers of the IPBES global assessment report on biodiversity and ecosystem services (IPBES, 2019), which states that "globally, local varieties and breeds of domesticated plants and animals are disappearing. This loss of diversity, including genetic diversity, poses a serious risk to global food security by undermining the resilience of many agricultural systems to threats such as pests, pathogens and climate change".

Moreover, IPBES states "reductions in the diversity of cultivated crops, crop wild relatives and domesticated breeds mean that agroecosystems are less resilient against future climate change, pests and pathogens".

Factual evidence on this is increasingly available. The FAO estimated that 75% of the varietal genetic diversity of agricultural has been lost in one century. As of 2014, around 6,000 plant species are cultivated for food production, but of these, less than 200 species had significant production levels globally, with only nine species alone accounting for over 66% of total crop production by weight (FAO, 2019). In parallel, more than 150 livestock breeds have gone extinct between 2010 and 2018 (ibid.). Such a genetic erosion of our nutritional base has considerable implications for food security, since relying on a narrow genetic base for nutrition makes food systems more vulnerable (Sunderland, 2011)

Wild food (food products obtained from non-domesticated species) is another important element of the biodiversity-food security nexus at global level (FAO, 2019). Wild foods contribute to food security both via direct consumption and as a source of income to purchase other food. Several wild foods have high micronutrients content, which can alleviate micronutrient and/or protein deficiencies. However, of the almost 4,000 species of wild food reported by countries worldwide as an important dietary complement, 24% are reported to be decreasing in abundance, being the actual figure probably worst since trends are either not reported or not known in 61% of the cases (ibid.).

Crops, at least partially, dependent on pollination account for 35 percent of global food production (Klein et al., 2007). Pollinated crops are vital global for food security also in relation to their importance as sources of micronutrients: 90% of the crops that provide vitamin C, 70% of those providing vitamin A and the majority of those providing, calcium, fluoride, and folic acid are pollinated by animals (Eilerset al., 2011).

Interlinkages with other drivers

Anthropogenic activities can have negative or positive impacts on biodiversity that will influence the provision of aboveground and belowground ecosystem services. Biodiversity is directly linked to environmental pollution and degradation, soil health, pests and diseases, competing land uses and, intensity of production. Biodiversity is negatively affected by climate change while playing an important role in climate adaptation, being key to mitigation of drought and floods, climate regulation, prevention of soil erosion and water filtration.

It is now widely recognized that climate change and biodiversity are interconnected, with possible negative consequences for human societies and well-being. Climate change can force species to migrate relatively small areas within their previous ranges, resulting in reduced genetic variability as well as a rise in human-wildlife conflict and spread of zoonosis and other infectious diseases (Abrahms, B. 2021).

Biodiversity loss is also strongly connected to environmental pollution and degradation, competing land uses and intensity of production. These drivers, in combination with demographic dynamics (population growth) and food demand/dietary choices (which are in turn connected to other drivers, such as food price) are leading to significant declines in biodiversity.

Presently, conventional agriculture accounts for around 90% of the agricultural areas in the EU. In those areas where intensive use of fertilisers and other inputs such as pesticides are used intensively this generally leads to a direct pressure on biodiversity. Conversely, landscape heterogeneity and organic farming practices can enhance flora and fauna richness or abundance in agroecosystems by more than 50% according to Stein-Bachinger et al. (2021).

Biodiversity is also potentially connected to investments in R&D, with technological advances offering promising tools to conserve or restore biodiversity, for example by using satellites and drones for arable crops to control pests, and smart farming to optimize the use of fertiliser, or by identifying and improving threatened habitats.

8.6. Research, innovation and technology

General context and what is at stake?

Research and innovation (R&I) are key enablers to providing solutions to future-proof our agriculture, fisheries and food systems to ensure food security and resilience. In this respect, R&I must catalyse all forms of innovation, such as governance and institutional innovation, social innovation, business model innovation, as well as technology innovation, for example to help farmers improve yields and soil fertility and manage nutrient flows. A systemic approach to R&I is furthermore needed to understand and address externalities and trade-offs, such as how agriculture and food systems affect and are affected by climate, environmental, health.

Knowledge transfer and reskilling is also needed to help farmers transition to more circular and resource efficient and sustainable practices. They are key to address all four dimensions of food security. Science-based solutions can not only mitigate pressure on resources without hurting production capacity in the long-term, but can also provides alternatives that can boost green economic growth and ensure long term competitive advantage to innovative primary producers and other food chain actors from farm to fork.

At the UN’s Food Systems Summit, held in September 2021, innovation was recognised as one of the keys to enabling food systems transformation. A joint statement by the Heads of FAO, IMF, WBG, WFP, and WTO on the Global Food Security and Nutrition Crisis recognised innovation as crucial for meeting the long-term challenges to global food security and nutrition posed by climate change, land and ecosystem degradation, pests, and transboundary plant and animal diseases.

Current assessment – 2022-24

The correlation between innovation and productivity growth is well established in the theoretical and evidence-based literature ([63]). R&I is boosted by public and private supports. Fuglie and Heisey estimate the mean rates of return to public investments in agricultural

([63]) Latruffe, L (2010)” Competitiveness, Productivity and Efficiency in the Agricultural and Agri-Food sectors”, *OECD paper on Food, Agriculture and Fisheries*, N 30, OECD Publishign Paris; OECD (2011), *Fostering productivity and competitiveness in agriculture*, OECD Publishing Paris research ranging from 20 to 60 percent ([64]). According to Eurostat, the EU-27 public expenditure on R&D in agriculture has grown by 1.4% on average between 2011 and 2020. However, the evolution of per capita public expenditure (in 2005 PPP) shows a certain stabilisation over time.

For the on-going 2021-2027 period, the EU has doubled the R&I support from its research and innovation programme for the food sector and enhanced the cooperation with other public and private initiatives. Under Horizon Europe (HE) around 9 billion EUR is invested in R&I to support Green Deal priorities in agriculture, food and the bioeconomy. New HE instruments, like the co-funded partnerships and Missions, such as the HE Mission 'A Soil deal for Europe' and 'Restore our Ocean and Waters by 2030' help to increase the R&I efforts in some key areas. In the framework of the co-funded partnerships Member States and the EU co-create and co-finance R&I actions in in key areas, for example for agro-ecology, the blue economy and sustainable food systems. Soil health is a key condition for food security. Under the Soil Mission, the EU provides 320 million Euro (2021-2023) for improving soil health. Beside the R&I objective of the Soil Mission, it also targets awareness raising on soil health issues in the EU and globally, and generates additional public and private actions and financing. Similarly, the Ocean Mission (EUR 320 million) aims at accelerating the implementation of key marine and maritime Green Deal targets and including contributing to ensuring food security.

New and existing technologies and innovative approaches can help raise crop and livestock productivity, improve soil fertility, increase water use and energy efficiency, and thus increase the amount of food produced per unit input. Technologies addressing post-harvest losses and food processing can address food accessibility and quality. Climate-smart solutions based on science, including via the use of precision agriculture and early warning systems can help mitigate food insecurity. Many of these approaches rely on sharing and analysing farm and food chain management data.

Research and innovation can help achieving sustainable fisheries and aquaculture and contribute directly to environment friendly, inclusive, safe and healthy food production by providing highly nutritional proteins, lipids and micronutrients for a healthy diets. Sustainable and resilient aquaculture systems, including the use of low trophic species (e.g. algae), high animal welfare standards and alternative sources of protein for food and feed, can increase seafood production and reduce its environmental impact while adding economic value to the chain.

The adoption of innovative solutions may be more challenging for producers and can be especially challenging for smaller farmers due to a lack of financial and human capacities and a lack of cost-effectiveness. Recent study results on the elasticity of substitution between labour, capital and land in EU agriculture, suggest however that innovation in physical capital alone is not sufficient to raise productivity, but it needs to be complemented with higher level and new labour skills,for example when it comes to digital technologies and precision machineries (Khafagy, M. Vigani, 2022). Consequently, education and training is another proxy for the uptake of new technologies and approaches. In this respect it is worth noting that close to 70% of all EU farm managers did not receive any formal agricultural training, while 9% has had a full agricultural training. This increases to 22% for the farm managers under 35 years old (2016 data).

([64]) Heisey, Paul and Fuglie, Keith, Economic Returns to Public Agricultural Research (September 2007). USDA-ERS Economic Brief No. 10, Available at SSRN: https://ssrn.com/abstract=1084926 or http://dx.doi.org/10.2139/ssrn.1084926

Farm managers training in agriculture, (EU27, 2016)

	Basic agricultural training	Full agricultural training	Practical experience only
All age groups	22,7%	8,9%	68,3%
< 35 years old	21%	22%	57%

Source: Eurostat

Harnessing the potential of diverse forms of innovation and technologies for food security not only requires investments in R&D but also in human capital, infrastructure, and knowledge flows (via education, training, advice, etc.).

In capture fisheries, investment and innovation can enhance the sustainability of fishing activities, for example by improving the energy efficiency of fishing vessels and lower their impact on the environment (e.g. on the seabed, habitats, sensitive species, non-targeted species). However, certain types of investments and innovation may be considered as harmful, as they may lead to increases in fleet capacity, which is not desirable considering the fully exploited or overexploited status of some fish stocks. Studies show that reducing food loss and waste would close the gap between the amount of food needed to adequately feed the planet in 2050 and the amount of food available in 2010 by more than 20% ([65]), thus contributing to improve food security. In the EU, the number of fishing vessels and the fishing capacity have been decreasing for many years ([66]). However, it is often claimed that due to the technological advances the fishing efficiency of the vessels has increased.

Forward looking – 2030

The latest OECD-FAO Agricultural Outlook projections (2022-2031) suggest that, in order to achieve the Zero Hunger target while simultaneously keeping agricultural emissions on track to reach the Paris Agreement targets, average global agricultural productivity would need to increase by 28% over the next decade, in a sustainable way. This is more than triple the increase recorded in the last decade. In order to achieve this, comprehensive action to boost agricultural investment and innovation and to enable the transfer of knowledge, technology, and skills are urgently required in order to put the agricultural sector on the necessary trajectory for sustainable productivity growth and the transformation towards sustainable food systems.

The increase of agricultural productivity in the EU will require important efforts to boost the use of the most advanced technologies among EU farmers, in particular the extension of precision agricultural technologies (sensors, ICT, robotics and data-driven decision support systems). Precision agricultural technologies (PAT) can contribute to food security by increasing productivity while reducing inputs per unit output (encompassing both natural resources such as soil and water, but also nutrient and agrochemical inputs), by improving management responses to weather variability (e.g. early warning systems) that reduce yield loss, by improved management due to networked data-analytics, to certification, and food traceability (Soto et al., 2019).

([65]) https://www.wri.org/reducing-food-loss-and-waste-ten-interventions-scale-impact

([66]) Fishing capacity is measured by the vessels' volume (in gross tonnage) and their power (in kW).

To fully exploit the potential of PAT, gaps need to be addressed in areas such as infrastructure/connectivity (e.g. broadband), farmers' awareness and skills, cost-effectiveness of certain technologies and trust of operators in technology and data sharing. This demands a comprehensive approach towards promoting PAT uptake.

However, even though a variety of benefits are associated with technology uptake in agriculture, experts advise that these new technologies should not be thought of as an alternative to agro-ecology (Agroecology Europe, 2021). They point to the cost of technologies and issues around overcapitalization of European farms. In addition, the adoption of the technology is low in many areas across the EU due to several barriers like high initial investment costs and long associated payback periods (Soto et al., 2019). In the medium and long term, if public policies support the mainstreaming of precision farming technologies, there is likely to be a larger uptake by medium and small-sized farms.

Also, New Genomic Techniques (NGTs) can bring speed to the development of improved varieties with traits that can support food security, such, increased yields, or reduced use of natural resources. This also requires a suitable legal framework as well as programmes that enable innovation to deliver on its potential.

The Commission's study on NGTs (NGTs, April 2021 ([67])) showed that plants obtained through these techniques have the potential to contribute to sustainable and resilient food systems, and thus contribute to food security in the EU, in line with the objectives of the European Green Deal and Farm to Fork and Biodiversity strategies. The Joint Research Centre report supporting the study demonstrated that NGT plant applications cover a broader range of plants with respect to other (transgenic) GMOs, e.g., vegetables, tubers, fruits and legumes. It also includes examples of NGT plants with traits that could contribute to various aspects related to food security (e.g. yield increase, reduced input use, and stress tolerance).

Increased efficiency of management of natural resources must also be supported by innovative food and bio-based value chains, in-line with the bioeconomy cascading use principle, including social innovations to speed-up the uptake of sustainable and circular production and consumption choices.

International dimension

Investments in research and development (R&D) are considered crucial to increase global agricultural productivity and food security, and continuous innovation in technologies and management practices facilitates the development of a more productive, resilient and environmentally sustainable food sector (Ruttan 2002, Alston 2009, Ademola 2019). To foster this, the OECD (2019) highlights the importance of strengthening linkages within the agricultural innovation systems (AIS), between R&D and technical assistance, as well as with R&D in other sectors, for example by enabling research co-operation and participation in networks. Research, education, and extension are important to bring knowledge, technologies, and services to farmers and entrepreneurs. However, the participatory concept of AIS is broader, as it needs to comprise a network of a wide range of actors (individuals, organisations, and companies), institutions and policies in the agricultural and related sectors in order make innovations widely available and bring them into use (World Bank 2012, OECD 2019).

([67]) https://ec.europa.eu/food/system/files/2021-04/gmo_mod-bio_ngt_eu-study.pdf

Well-established AIS are especially important in developing countries, as technology adoption and innovation amongst small-scale farmers remains relatively limited. It is worth noting, however, that this lack of diffusion of certain technologies, typically focused exclusively on increasing yields, may imply that they are not necessarily beneficial to many farmers in developing countries. The agricultural R&D process would therefore benefit from shifting some attention away from the yield gap to farmers' overall gains in a broader sense and from incorporating preferences of farmers earlier into the research production process (Macours, 2019). In addition, technology adoption decisions are influenced by socio-cultural factors. Thus, socio-cultural values and institutions need to be considered within AIS (Curry et al. 2021).

Agricultural R&D tends to be concentrated on staple foods, especially cereals. The limited amount of research devoted to non-staple food crops could hamper the development of a nutrition-sensitive food system, especially in developing countries. Accordingly, there is need to increase investment in agricultural research on micronutrient-rich non-staple crops (Pingali and Sunder 2017, Anderson and Birner 2020).

The ongoing process of innovation with respect to modern genetic and information technologies to increase agricultural productivity is an important factor to contribute to food security while at the same time balancing sustainable outcomes associated with agricultural production ensuring a fair distribution of incomes and tackling potential access restrictions such as intellectual property issues. Digital agriculture (a set of digital and geospatial information technologies integrating sensors, analytics and automation to monitor, assess and manage soil, climatic and genetic resources at field and landscape scales), is advancing rapidly and has the potential to support sustainable food systems in both developed and developing countries (Basso and Antle 2020).

Interlinkages with other drivers

Investment in research and innovation, technological development, knowledge transfer and reskilling are horizontal drivers, since they act as enabling factors to achieve higher efficiency in food production, while minimising negative effects on natural resources.

8.7. Intensity of production

General context and what is at stake?

Intensity of production is the ratio between the quantity of input needed for the production and a unit of final product for a given land area. It directly affects production levels and hence food availability. Changes in relative prices (output, input) can move the equilibrium towards a different point where input intensity changes, with a direct impact on production. Intensive agriculture is characterised by low input of land but very high inputs of capital investment and chemical fertilisers, pesticides etc. (i.e. capital intensive farming).

EU agricultural total factor productivity growth is slowly, but steadily growing (EU Agricultural Markets Briefs, 2016), averaging 0.8% annually in 2005-2015 compared with 1% per year in 1995-2005. Similarly, over the period between 2005 and 2020, there was an upward trend in the output volume of the EU's agricultural industry (a total increase of +12.3 %). But to a large extent, higher output volumes were underpinned by a relatively steady rise in the volume (+8.0 %) of input goods and services consumed.

While the output of the agricultural industry in the EU has increased the consumption of input goods and services has thus increased as well. These medium-term trends point to some but rather limited evidence of the decoupling of output growth from resource use at the EU level (Eurostat, 2022).

In the global context of a growing population, food security and natural degradation, there is general agreement in the scientific community that the efficiency of agricultural production needs to increase in order to meet global food demand while at the same time reducing or minimising impacts on natural resources and ecosystems (Cassman and Grassini 2020).

To achieve this, different methods and approaches can contribute, from traditional management techniques like soil and nature conservation to the application of enhanced technologies and management practices (Cassman and Grassini 2020). Increasing productivity (yields) using fewer inputs while having positive environmental and social impacts (Garnett et al. 2013, Pretty and Bharucha 2014) is a considerable challenge.

However, it is also recognised that while improvements should be made at the production stages of the food chain – much can be done further down the supply chain and on the consumption-side including improved distribution, reduced food waste and change in diets.

Current assessment – 2022-24

The level of intensity type of farming in the EU-27 is shared almost equally between the three broad classes, high, medium and low intensity farming. High and medium intensity farming occupy a share of 36% each, while low intensity farming occupies the remaining >30% . The share of organic farming is showing an increasing trend in EU-27.

In the traditional and outdated approach, intensity of input use would directly affects food availability.

However, farmers may adopt less-intensive crops or production activities (e.g. incorporating legumes in their crop rotation), for which production levels can then increase. Conversion to higher value-added production regimes such as organic farming can also contribute to maintenance of farm viability and quality food production with lower inputs. Moreover, more efficient use of inputs can help to maintain production levels even with lower production intensity. This concerns, for example, stringent nutrient management plans for fertiliser application.

Input subsidies could help temporarily, but they would also hamper the adjustment farmers would naturally undergo to adapt to the new economic conditions, while also implying an additional budgetary burden for governments.

Forward looking – 2030

To improve the resilience of food systems, diversification along the full supply chain and at different levels of organization is needed (Hertel et al., 2021). Diversification throughout the food system and identifying where critical redundancy needs to be built in will also provide resilience to stresses and shocks, including those from climate impacts, benefitting access, availability, and stability of food supply.

In the medium- to long-term, farmers can further increase the efficiency of inputs so that they can reach higher levels of production with the same amount of fertilisers, or the same level of production with lower inputs including both fertilisers and plant protection productions. This can be achieved with technical progress or changes in management practices (Levers et al. 2016). In addition, although mostly associated with a decrease in production intensity, the envisaged ecosystem restoration in the EU can have positive impacts on food productivity in the longer term (Liquete et al. 2022).

International dimension

Intensity of agricultural production varies extensively across the world, from low-input agricultural systems in low-income countries such as Sub-Saharan Africa (SSA), to high-input farmers in industrialised countries but also in middle-income countries such as South-East Asia.

Using global crop model simulations wheat production potentials and remaining management flexibility have been identified (Balkovic et al., 2014). These simulations illustrate that the intensification potential remains high in Eastern European Union Member States. On the other hand, limited management flexibility remains in areas characterized by intensive agriculture in the EU.

Many countries in the world are extremely dependent on imports for their supply of agricultural inputs, and notably for fertilisers. This is the case for most of the South American countries, which are important agricultural commodity suppliers, and where the high price of fertilisers and energy could have significant impacts on overall intensity of production.

Almost all SSA countries rely entirely on imports for the supply of chemical fertiliser, however, the share of farmers using fertiliser is lower, and therefore production impacts may be more limited. Given support and incentives there are ample opportunities in developing countries to increase productivity, which would considerably improve food security and is particularly relevant in the concept of 'sustainable intensification' of agriculture (Foley et al. 2011, Pretty et al. 2011, Muller et al. 2012, Folberth et al. 2020) or in the concept of agroecology which has more emphasis on the mobilisation of ecological processes, biodiversity and recycling of nutrients at crop, farm and. landscape level (HLPE 2019).

Interlinkages with other drivers

The intensity of production is directly affected by input prices and possible supply chain bottlenecks but also by R&I investments to identify alternative solutions. Higher prices or supply disruption impact negatively the use of inputs and consequently the intensity of production. Thus, the food security driver intensity of production is directly linked to the drivers related to fertiliser and energy prices, food supply chains, access to funds, and investment, technology and innovation, and availability of workers and skills. Moreover, intensity of production is interrelated with environmental drivers including pests and diseases, soil health, and climate change, as well as with food inflation, farm income, and trade.

8.8. Trade

General context and what is at stake?

Trade allows moving food commodities from surplus producers to deficit countries, contributing to keep prices lower than in a self-sufficiency state and have an overall positive impact on global food security. Conversely, trade barriers due to trade and market interventions can undermine the availability and affordability of nutritious foods (FAO 2022). Against this background, open and free trade is essential to allowing unrestricted flows of fishery and aquaculture products. Without open and free trade and well-functioning global food supply chains, food security is at risk. Taking into ac-count challenges impacting trade in the context of a sustainable and fairer globalisation, like for example climate change, environmental degradation, and growing international tensions, the EU aims at establishing a new consensus for trade policy based on openness, sustainability and assertiveness (EC 2021) ([68]).

In general, open and fair trade facilitates the flow of food from surplus to deficit countries, which is essential for food security in many net importing countries (Fader et al. 2013; Porkka 2013, 2017). Trade liberalization can affect nutrition and health via its impacts on food prices and availability (Hawkes et al. 2015). Trade can also have adverse side effects, as it, for example, may impede the domestic potential to improve food security if domestic farmers cannot compete with lower prices or higher standards (Brooks and Matthews 2015). Nevertheless, even in the concept of food self-sufficiency the positive effects of trade are not rejected (Clapp 2017), and especially for countries with scarce water and land resources, food imports are essential for food security (Fader et al. 2013, Araujo and Fellmann 2020; Janssens et al. 2020). Trade integration and food import dependency, however, makes countries also more vulnerable in case of sudden disruptions of trade flows and price volatility (Headey 2011; Puma et al. 2015; BrendÁmour et al. 2016).

In 2021, the EU share of agricultural products in total trade was 9% in 2021. The value of total trade (imports plus exports) of agricultural goods between the EU and the rest of the world (i.e., extra EU trade) was EUR 347 billion. With exports accounting for EUR 197 billion and imports for EUR 150 billion, EU trade in agricultural products generated a surplus of EUR 47 billion. Between 2002 and 2021, EU trade in agricultural products more than doubled, with an average annual growth of 4.8 %, and exports (5.4 %) growing faster than imports (4.2 %) (Eurostat 2022).

The EU's top three agri-food export categories are cereal preparations & milling products, dairy prod-ucts, and wine & wine-based products, representing about 26% of EU export value in calendar year 2021. The three categories recorded the highest trade surpluses, accounting for EUR 15.3 billion for dairy products, and EUR 15.0 billion for each wine & wine-based products and cereals preparations & milling products, followed by pork, which reached a trade surplus of EUR 14.2 billion in 2021 (Euro-stat 2022).

The most important import categories are seafood products (EUR 25.82 billion in 2021), fruits and nuts (EUR 20.7 billion in 2021), oilseeds and protein crops (EUR 18.3 billion), coffee, tea, cocoa and spices (EUR 17.1 billion), and vegetable oils (oilseeds and palm, EUR 8.2 billion), representing 16%, 14%, 13%, and 6%, respectively, of the total import value of agri-food imports (EC 2022).

The EU is highly dependent on external trade to satisfy its high demand for seafood products. The EU imports more than 12 million tonnes of seafood for human consumption, measured in live weight equivalents, while it exports almost 9 million tonnes. Thus, net imports of seafood for human consumption are above 6 million tonnes. In 2021, extra-EU imports of seafood products totalled EUR 25,82 billion. On a longer perspective, when comparing 2012 with 2021, total imports rose by 25% in value in real terms. Extra-EU exports play a far less important role, which makes the EU a net importer of fishery and aquaculture products. EU exports to third countries reached EUR 6,75 billion, showing an increase of 11% in real terms if compared with 10 years before (EUMOFA 2022). On average, around 10% of EU catches (but much more

([68]) https://trade.ec.europa.eu/doclib/docs/2021/february/tradoc_159438.pdf in the case of tuna species) are made under fisheries agreements with countries outside the EU, while another 10% are taken on the high seas, mainly in regions under the care of regional fisheries management organisations.

In order to reply to this high demand for seafood products on the EU market, the EU's long-standing policy has been to provide for autonomous tariff quotas for fishery products (ATQs). They reduce or suspend import duties for a number of fishery products within tariff quotas of an appropriate volume. Besides, in the past 15 years, the EU has negotiated, signed and implemented Free Trade Agreements with many partner countries. Most of these FTAs provide for market access concessions regarding fishery products. These concessions may consist of full tariff liberalisation, partial tariff liberalisation, staging or tariff rate quotas for fishery products.

Current assessment – 2022-24

Within the global context, the EU is a significant producer and the main exporter of agri-food products in the world: while the EU is mainly oriented towards the export of high value / final agri-food products, its contributions as an exporter of key commodities, such as cereals, and in primis wheat, as well as dairy products, pig meat, and certain fruits and vegetables is also substantial. As such, the EU plays a major role in supplying staple food to import-dependent countries all over the world, in particular developing countries.

At the same time, the EU is also one of the major importers of agri-food products, both of final goods that are not produced in the EU (such as tropical fruits, coffee or cocoa) or not in sufficient quantities (such as fishery and aquaculture products), and of key agricultural intermediate inputs, such as vege-table proteins (soya) and cereals (maize) that is used as feed for its livestock production. Given the consumption levels in the EU and the constraints in production both in terms of land availability and agro-climatic conditions, the EU does not have the capacity to achieve full self-sufficiency in these products. Well-functioning and integrated trade enables and facilitates the exchange of commodities, and considering aspects of productivity and efficiency in the production of agri-food products, trade enhances global food security by contributing substantially to food availability and access.

The cereals market situation following the invasion of Ukraine by Russia clearly shows that bottlenecks in the trade flows of key agricultural goods, such as the disruption of Ukraine exports due to the block-age of the Black Sea ports, can have significant negative impacts on world grain market prices, and thus on global food security. Trade-restrictive policy measures adopted by some countries, such as export bans or taxes on key agricultural goods (e.g., cereals, oilseeds and oils) or on key inputs necessary for agricultural production (e.g., fertilisers, energy prices) have also driven global commodity prices. These measures, often referred to as "beggar-thy-neighbour", aim to increase food security in the country implementing it, but have the effect of harming importing countries and global value chains. The food crisis of 2007-2008 started escalating just after a number of countries adopted bans or other export restrictions, notably on wheat and rice, following the initial tensions on the cereals markets.

Moreover, shortages and high prices of key raw materials and inputs are affecting the fish processing sector (e.g. sunflower oil) and aquaculture sector (e.g. fish feed) as Ukraine and Russia are major global suppliers of these goods. Shortages are also expected for substitutes due to competition from other food sectors and from bioenergy production. This negative supply shock is leading to increased prices.

Forward looking – 2030

In its Trade Policy Review Communication ([69]), outlining the future orientations of EU trade policy, the Commission has stressed the role of trade openness within the concept of "Open Strategic Autonomy", notably recalling the importance of an open and fair trade with well-functioning, diversified and sustainable global value chains. In that respect, free trade is essential to strengthen resilience and support the competitiveness of its domestic food industry. At the same time diversification of import sources and market outlets is key to avoid bottlenecks and vulnerabilities due to excessive dependence from a limited number of trade partners, be it on the one hand for importing key commodities for food security or inputs necessary for the agricultural, fishery and aquaculture production (feedstuff, but also fertilisers and energy goods), and on the other hand when exporting food products.

International dimension

Trade is allowing production to move from areas of surplus to areas of shortage, and a liberalised, open and fair, trade environment for agricultural commodities can have substantial overall economic and food security benefits (Smith and Glauber 2019). However, trade integration also implies increased exposure to trade interruptions on the international market. Such interruptions could be specifically observed during the global agricultural price spikes in the years 2007–2008 and 2010–2011. In these two periods, the effects of harvest failures in major grain exporting countries were augmented by temporary export restricting policies that put further pressure on international prices and both food availability and access (Mitra and Josling 2009; Anderson and Nelgen 2011; Headey 2011; Fellmann et al. 2014; Giordani et al. 2016).

Trade restricting policies imposed by countries have also surged following the start of Russia's war against Ukraine. The global food security crisis has been partially made worse by the growing number of food trade restrictions put in place by countries with a goal of increasing domestic availability and reducing prices. As of 15 September 2022, 21 countries have implemented 30 food export bans, and six have implemented 11 export-limiting measures (World Bank 2022). As mentioned above, such policies should be avoided as they have harmful effects on importing countries, particularly the most vulnerable. Furthermore, an increase in transparency of the markets should benefit food security by providing a more stable and predictable economic (or less volatile) environment.

An increase in consumption demand for animal products, such as cheap seafood products has been observed together with increases in income and purchasing power in emerging economies (e.g. China and Brazil) (Gerbens-Leenes et al. 2010). Continued increases in income and urbanization in develop-ing countries, may lead to higher seafood prices and changes in traditional trade relations between countries. Consequently, the seafood consumption in areas that currently benefit from high imports (e.g. EU, Japan and USA) may decrease.

Interlinkages with other drivers

Trade as driver for food security is directly interlinked with many drivers. Most importantly, increase of trade and trade openness generally have positive effects on supply chain efficiency, food prices and household income, increasing food availability and access. Moreover, as these effects also increase the choice possibilities, trade can also positively affect dietary choices of consumers (food utilization). In general, exports and imports can also have opposite effects on food security drivers. For instance, trade can reduce the price of agricultural inputs (feed,

([69]) Communication on the Trade Policy Review (europa.eu) fertilisers and energy), reduce food prices for consumers and, at the same time, offer opportunities for farm income by providing new export out-lets. Conversely, in some cases, increase of food imports may compete with domestic production, thus decreasing domestic agricultural prices and producer income (see, e.g. Ecorys 2021).

8.9. Speculation in agricultural commodity markets

General context and what is at stake?

Recent price developments of agricultural products, in particular cereals and oilseeds, are causing concerns by some stakeholders that excessive speculation by investment firms and funds in agricultural commodity markets contributes to price increases and volatility and, hence, increase pressure on food access (affordability). In its Trade and Development Report 2022, UNCTAD, for example, points out that further attention needs to be paid to the role of speculation in the futures market.

Well-functioning agricultural commodity futures markets play an important economic role, as they help producers, merchants, and processors (the so-called commercials or hedgers) to hedge against price changes (i.e. they reduce price risks). Financial speculation seeks profit from price fluctuations, with speculators (also called non-commercials) not having a specific interest in the use of the commodity (i.e. they have no interaction with the physical commodity). By increasing market liquidity and bearing some of the risk, financial actors contribute to the correct functioning of markets. Accordingly, excluding food commodities from speculative transactions would impede risk-sharing and slow down price discovery processes.

Under normal conditions, speculation does not destabilise markets, in particular when markets have a high level of transparency.

Regarding the general impact of speculation on commodity prices, Palazzi et al. (2020) conducted a literature review to analyse the relationship between index funds and commodity prices. They conclude that the literature does not agree on how speculative funds influence the commodity markets. Lawson et al. (2021) similarly state that the role of financial speculation on food prices is unclear in the literature, concluding that results on the topic may differ depending on the commodity analysed. Boyd et al. (2018) find that, while there is a theoretical possibility of speculation destabilising physical commodity markets, there is little evidence for this effect. Irwin et al. (2009) point out that there is not necessarily a link between activity in futures markets and demand for that commodity, as the supply possibilities for futures contracts are unlimited, and each new futures contract simply represents a match between a short and a long position.

The current price surge shows parallels to the situation in 2008-2011, but the drivers are different. The empirical evidence on whether financial speculation contributed to the price spikes in 2008-2011 has been mixed and inconclusive. For example, Robles and Cooke (2009) and Gilbert (2010) found empirical evidence that futures market activity likely contributed to increased spot prices. However, the statistical tools used to derive these findings are debatable, such that Headey (2011), for example, expresses criticism regarding the Granger causality method used to reach its conclusions. Furthermore, Irwin et al. (2009), Irwin and Sanders (2011) and Haase and Huss (2018) found contrary pieces of evidence to Robles and Cooke (2009) and Gilbert (2010). Headey and Fan (2008) and Bohl and Sulewski (2019) even indicate that commodities with less speculative capital often had higher price increases than commodities with large speculative capital. Ott (2014) finds that the derivatives market activity did not have a significant effect on either intra- or inter-annual volatility of cereal prices. In contrast, large cereal stocks and a well-functioning international cereal market reduce the effects of shocks on both intra- and inter-annual volatilities. In general, there are many studies that emphasise that factors other than speculation had a greater effect on the price spikes in 2008-2011, e.g. crude oil prices, export restrictions and low stocks (Heady and Fan 2008, Naylor and Falcon 2010, Heady 2011).

The current price surges also require a deep assessment, including through the use of appropriate econometric techniques. Although this might come to equally diverse conclusions than in the previous cases, as mentioned above, it cannot be excluded that financial speculation had an effect on recent price dynamics.

Current assessment – 2022-24

One indicator for increased speculation can be changes in the composition of market actors trading an agricultural commodity. Data shows that the share of non-commercial traders in wheat and maize increased significantly since the end of 2020. However, this alone does not establish an increased influence of financial market speculation on commodity futures prices, as it could also only show increased liquidity. As such, rather than indicating a direct influence on prices, a growing share of non-fundamental speculators increases the risk that price formation becomes disconnected from market fundamentals and more strongly influenced by non-agriculture macroeconomic drivers.

A further important indicator to be combined with the market composition is the net position of speculative funds published by the Commodity Futures Trading Commission (CFTC) on a weekly basis. However, this net position does also not allow drawing definitive conclusions. On the one hand, for example in wheat, currently the net speculative position is neutral (i.e. close to zero), which means that speculative funds do not hold an important position that could potentially have a significant impact on prices. On the other hand, the net speculative position in maize and soybeans is long since the end of 2020. In the latter context, it is important to note that especially mid- to long-term investment strategies often follow the fundamentals in agricultural markets. In other words, by holding a long position in maize at current levels, many investment funds believe that given the current supply and demand of maize, prices for maize should be even higher in commodity markets. Hence, they buy futures at current levels, and hold a long position, which solely reflects their views on under-priced market conditions.

Forward looking – 2030

Among the measures frequently mentioned in the scientific literature that may help to preserve the integrity and functioning of food commodity markets are (i) market information, diagnostics and transparency, enhanced with information systems on emerging risks (as e.g. provided by the JRC MARS bulletins, data publication through the Agri Food Data Portal or the Agricultural Market Information System (AMIS), and the agricultural markets observatories); (ii) keeping food markets open to international trade and enhancing cooperation across nations for stock releases, as well as countries cooperation on the exchange of market information such as for example AMIS; and (iii) more harmonized and clearer rules for the trading of agricultural commodities futures including strengthening regulation of futures markets such as position limits or some controls to limit high-frequency trading. In the EU, these provisions are mainly included in the Markets in Financial Instruments Regulation and Directive and the Market Abuse Regulation and Directive.

International dimension

The potential role of speculation on the market is global by nature. If there would be a demonstrable impact of speculation on the market, less stable, more trade-dependent economies would suffer more from inflated food prices.

Interlinkages with other drivers

The link between speculations in agricultural commodity markets and the other drivers is not fully clear as in most cases it depends on the link between speculation funds and prices, which as stated previously, is not established in the relevant literature. Assuming that there would be indeed an impact of speculation on market prices, this would be directly interlinked with farm income, food prices, and trade and it could also affect the intensity of production or land use. The interlinkage to these drivers cannot be classified as negative nor positive. For example, if we assume speculation has an impact on prices and hence farm income, it is not necessarily positive, because if speculation would increase prices, then farm income would increase, but if, additionally, speculation would lead to more volatility or depressed prices then it could negatively affect farm income. While speculation on agricultural commodity markets has no direct impact on energy prices, it should be pointed out that speculation can also occur in energy markets and if energy prices are high and volatile, they can attract more speculation with adverse effects on fertiliser prices as well as farm and household income.

8.10. Energy prices

General context and what is at stake?

The entire food chain needs reliable energy supplies, both for its own production needs, transport, processing and for the production of inputs. The needs range from natural gas for fertiliser production, fuel for vessels, tractors and trucks, gas and fuel to heat greenhouses, gas and electricity for heating and cooling operations in the food industry and energy sources for logistics, and food delivery and retail. Energy represents a considerable share of production costs for the farming and fishery sectors and higher prices for energy can lead to lower primary production output and higher prices of agricultural, fishery and aquaculture products. So far, energy used in the food chain is largely based on imported fossil fuels which makes the EU food system very vulnerable to energy supply shocks. Integrated renewable energy production in on-farm activities would reduce that vulnerability, while aiding collectively to the targeted share of energy from renewable sources in the EU's gross final consumption of energy in 2030 of at least 32 %. ([70]). While increased primary commodity prices also impact consumer food prices, retail prices are generally more impacted by higher energy costs in the food processing, distribution and marketing stages.

International energy prices in general, represented by the IMF Energy Index, are still not as high as they were in 2008, but they have increased significantly the last couple of years. The Brent crude oil price remains very volatile, it has increased from around EUR 40 per barrel (b) in 2020 to around EUR 100/b in 2022, reaching a peak of 120 in June to progressively decrease to about EUR 90 in October. The price of coal and gas, which is used to produce electricity, has also spiked. The World Bank’s Natural Gas index for August, for example, is more than four times as high as the 2020 average. Specifically, the European reference gas price for February 2022 was more than ten times higher than the 2020 average. The US reference gas prices, in comparison, have gone up only by a factor of 2.5 in the same period.

([70]) RED II

Current assessment – 2022-24

Disruption of energy supplies can in many cases negatively affect the different stages of the food chain and, in turn, impact vulnerable consumers through higher food prices. The EU fisheries fleet is highly dependent on energy prices and supply, with energy (marine fuel for fishery and electricity for aquaculture) being fundamental to guarantee supply of Fishery and Aquaculture Products (FAPs), contributing to FAPs availability.

The upward pressure from high energy prices on agricultural and fisheries producer prices is not expected to ease in 2022, with some more optimistic prospects in the second half of 2023. These are continuing upward pressures on production costs, for instance electricity, transport, cooling and heating, as well as fertilisers and other inputs. Fossil fuel markets are due to remain tight and uncertain, and prices are expected to stay high in 2022. Oil price pressures are projected to abate in 2023 on addition-al supply coming online in non-OPEC countries and on weaker global outlook. EU natural gas prices have peaked since Russia delivered reduced volumes. Due to the importance of Russian gas supply for the EU and because the movement of gas is relatively inflexible in the short term due to limited availability of pipelines. As demand for gas is highly seasonal in the EU, gas storage is considered as particularly important to alleviate further short-term gas price pressures, which is why the EU introduced a new legislation that required Member States to fill their storage facilities to at least 80% by the start of winter 2022. In the short term, energy savings and efficiency improvements both on-farm and along the supply chain can help in minimising impacts of high energy costs.

The REPowerEU plan is set to reduce dependency from Russian fossil fuels, and features a set of short, mid, and long-term aims. Demand reduction plays an important role in the short-term goals of the plan and among the short-term measures are, for example, modifying energy pricing to encourage lower energy use and fuel, creating new energy partnerships with reliable suppliers, and increasing the production of biomethane.

The Communication "Ensuring availability and affordability of fertilisers" published on 9 November 2022 outlines measures to maintain a sustainable European fertilisers' production, optimise use and reduce dependency on mineral fertilisers.

Forward looking – 2030

Looking forward, the global outlook for energy and non-energy commodities is for progressive moderation, even if oil prices are expected to remain bullish in the medium-term (Brent barrel at around 90-100 USD). The EU has several legislations and initiatives in place that aim at reducing energy use and target a more sustainable energy supply. Lately, REPowerEU aims at saving energy, producing clean energy, and diversifying EU energy supplies..

International dimension

Many studies in the literature assessed the issues related to energy prices and food security over the past decades. Addressing the linkage between energy prices and agricultural commodity prices, energy prices have been found to have significant impacts on food prices, with higher energy prices leading to food insecurity, especially in vulnerable economies. High energy prices have, for example, been identified as one of the main drivers of the agricultural price spike of 2008/09 (Heady and Fan 2008). Moreover, increasing energy prices have been found to have a higher and longer-lasting effect on food prices than a decrease (Chowdhury et al. 2021). While the share of energy inputs in the production of agriculture commodities, and food in general, can vary considerably across regions, higher energy prices inevitably imply higher production costs, and ultimately lead to higher food prices. In addition, high energy prices can also lead to lower input use levels (e.g. fertilisers), putting additional pressure on global food security (FAO et al. 2022). The interlinkages between food, energy and finance are also emphasised and explained in the reports produced by the UN Global Crisis Response Group on Food, Energy and Finance. A better use of policy support for activities in agrifood systems can contribute to a solution, for example by supporting more efficient use of energy in agrifood systems, investments in renewable energy sources at the farm level, or the introduction of freight truck fuel economy standards at the transportation stage (FAO 2011, IEA et al. 2021, FAO et al. 2022,). Furthermore, improvements in technologies and the operation and management of energy-intensive cold chain logistics can be key to reduce pressures for food security in the context of high energy prices (with positive implications for reducing pressures from the food security driver food loss and waste (Han et al. 2021).

Interlinkages with other drivers

The driver "energy prices" is directly linked to several other food security drivers. Higher energy prices directly increase prices for fertilisers, lead to increased costs along the food chain and increased production costs in the farming and fisheries sectors, with adverse effects on income. These interlinkages drive food prices. Moreover, high energy prices directly impact household income. Conversely, if high energy prices lead to a reduction and more efficient use of energy, this may have positive effects on the food security drivers climate change, and environmental pollution and degradation.

8.11. Fertilisers

General context and what is at stake?

Nutrients are essential for healthy plant growth. The primary macronutrients plants need are nitrogen (N), phosphorus (P), and potassium (K). Agricultural plant species extract and export these nutrients from the ecosystem, thereby depleting the soil. Fertilisers and other soil improvement products (manure, compost, crop residues) add nutrients back to the soil and allow plants to reach their growth and yield potential. This decreases land pressure as it increases food production.

The EU is largely dependent on imports of mineral fertilisers, importing about 30%, 68% and 85% of its consumption of inorganic nitrogen, phosphates and potash nutrients respectively. In the absence of nitrogen-based fertilisers (produced with gas), agricultural output in the EU could be affected and commodity prices could further increase compared to a situation with ample access to fertilisers. Russia and Belarus are the largest exporters of Potash (K) fertilisers, from which the EU is largely dependent. Russia is also one of the largest exporter of Phosphate (P) fertiliser. Russia’s war against Ukraine induced disruptions in affordability and availability of fertilisers, with adverse effects on the production of certain agricultural commodities (Hellegers 2022). Furthermore, reduced import possibilities from Russia and Belarus increase the EU’s reliance on its other suppliers (e.g., Morocco, Egypt), which do not provide the same quality (e.g. they have a higher cadmium content than EU limits).

Pressure on fertiliser markets is also stemming from high energy prices. Natural gas is needed in large quantities to produce nitrogen fertilisers. Due the high energy costs, fertiliser companies are reducing their production. This leads to further shortages and fertiliser price increases, leading to farmers buying and using lower quantities of fertilisers on their crops, where no alternative solutions exist. This entails a risk of lower yields and could hence impacts on food availability and access.

Fertiliser costs have an important share in EU crop farmer's production cost, although this depends on the year and the crop. Fertiliser requirements depend on crop varieties as well as actual production and farming practices methods. The production of nitrogen (N) fertilisers is highly energy intensive: its important feedstock is (fossil) natural gas. The price for natural gas amounts to about 70-80% of the production costs of fertilisers. Imports into the EU account for 36% of urea and 30% for nitrogen solution consumption. Moreover, 34% of urea imports used to come from Russia, Belarus, and Ukraine, while the share was 45% for nitrogen solution. Imports of natural gas (an important feedstock for all nitrogen fertilisers) from Russia amount to around 40% of the EU's total gas consumption. Phosphorus deposits are mostly located outside Europe (closest producing countries being RU and Morocco). The EU imports 68% of its phosphorus needs (20% of this from RU). As for potassium, the EU has an import dependency of 19%, and Russia and Belarus account for 55% of the EU's imports (Canada and Israel account for 36%). After the surge in fertiliser prices in the second half of 2021 and since Russia's invasion of Ukraine started, there was another 50% spike of aggregate fertiliser prices (potash and phosphates prices increased in particular).

The median energy and fertiliser shares of total input costs across EU Member States and years are 8 and 6%, respectively but there is a considerable variation in the cost shares across countries and years. Median intermediate cost shares are 12 and 9%, respectively, and median fertiliser total specific and crop specific costs are 14 and 37%, respectively.

Current assessment – 2022-24

High import dependency and high energy costs put the fertiliser supply under strain. The recent gas price hike ([71]) has led to a spike of fertiliser prices and thus a significant increase in agricultural production costs. Short-term solutions consist of more targeted and efficient use of fertilisers on farms (e.g. nutrient management plans, soil conservation programs, precision agriculture) and closing of nutrient cycles, in line with the Farm to Fork (F2F) target to significantly reduce nutrient losses. If gas prices stabilise at the current very high levels, producing nitrogen fertilisers with imported gas may require subsidising either fertiliser or gas buyers (or otherwise some producers may take the decision to disinvest). Consequently, beyond the important impact of subsidies for public finances, the EU risks becoming even more dependent on imported fertilisers, with the ensuing risks for EU food security. Currently, several MS are subsidising gas and electricity consumption at the household level (lower VATs and top-up prices) and costs for big businesses that are heavily dependent on energy to avoid insolvencies. This heavy regulatory framework poses some uncertainties all through the food chain, from the fertiliser producers to the food retailers.

In a Communication in November 2022, the Commission set out a plan on how to ensure the availability and affordability of fertilisers ([72]).

Forward looking – 2030

([71]) The average natural gas price in the EU between 2010 and 2020 was 8 USD/mmbtu (Metric Million British Thermal Unit), compared to 3 in the US, in 2021 this quotation climbed up to 16 USD/mmbtu (4 in the US) and in August 2022 reached 70 USD/mmbtu (9 in the US) (see https://www.worldbank.org/en/research/commodity-markets).

([72]) https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52022DC0590(01)

For the fertiliser industry, the most critical step will be the green transition, for which using green hydrogen ([73]), digestate ([74]) from anaerobic digestion for biogas (and biomethane) and compost from various bio-waste sources are promising avenues. Yet, the need for large quantities of renewable electricity presents challenges similar to those facing the gas-based production of fertilisers. The most critical step at the level of agricultural production seems to be the better targeting and efficient use of fertilisers on farms, as this reduces the need for (and dependence on) fertilisers and contributes to lowering nutrient losses to the environment.

International dimension

High fertiliser and other input prices are an international problem for agricultural production and food security. A large amount of fertiliser is traded on international markets, with most fertiliser sourced by only few countries. Russia's war against Ukraine its rippling effect notably on export restrictions in-creased trade costs and uncertainty about Russian and Belarus exports, putting particular pressure on international fertiliser trade. Globally, about 75% of all countries depend on imports for 50% or more of their fertiliser use (FAOSTAT 2022) and, therefore, distress on the fertiliser world market spreads fast and impacts farmers globally. Although price shocks may be mitigated in countries with subsidies for fertiliser use, this also implies increased fiscal pressure, while many fertilisers' subsidies scheme are not efficient.. In general, risks around fertiliser availability and affordability vary by country and region (Sub-Saharan Africa, with a low level of fertilisers consumption, but also Asia and Latin America, where usage is higher) and crop (some crops, e.g. maize and irrigated rice, require more fertilisers than e.g. vegetables). Notably, Africa accounts for only 3-4% of the global fertiliser market. Even if a significant part of small farmers in developing countries are not buying fertilisers, many farmers are likely to be negatively affected as their potential crop yields suffer, which adds to food security concerns in low- and middle-income countries (Bentley et al. 2022, Bonilla-Cedrez et al. 2021). Possible ways to counter the situation include improving the efficiency of fertilisers' use, developing more sustainable farming practices, including cultivation of leguminous crops, and adopting an agro-ecological approach.

Interlinkages with other drivers

Fertiliser prices are directly linked to the driver of energy prices, with higher energy prices leading to higher fertiliser prices. In the same way, higher fertiliser prices increase production costs for farmers, which negatively effects farm income and leads to increases in food prices. Furthermore, high fertiliser prices lead to decreases in trade, and may also lead to increased speculation in agricultural commodity markets. Conversely, if high fertiliser prices lead to a reduction and more efficient use of fertiliser, this may have positive effects on the food security drivers biodiversity and environmental pollution and degradation.

8.12. Pesticide use

General context and what is at stake?

Crop protection is pivotal to safeguard food security. Globally, significant shares of harvests are lost to pests and diseases (Savary et al. 2019, Oerke 2005), whereas losses in the EU are

([73]) Hydrogen produced by splitting water into hydrogen and oxygen using renewable electricity. Hydrogen is mixed with nitrogen from the air to produce ammonia, which is further processed into fertiliser. Conventional ammonia-based fertiliser uses hydrogen derived from natural gas.

([74]) Digestate is degraded organic matter under anaerobic fermentation process, representing a complementary product of anaerobic digestion, together with biogas.

considerably lower. Minimizing these losses could solve part of the supply constraints to feed the world. While farmers apply a multitude of agronomical and technological strategies to minimize pest and disease impacts in their fields, currently a key tool remains the use of pesticides (Aktar et al. 2009, Sharma et al. 2019). Farmers apply millions of tonnes of pesticides on fields across the world (Sharma et al. 2019, FAOstat). In the EU, 346.000 tonnes of pesticides were used in 2020 (ESTAT). The term pesticide commonly refers to herbicides, fungicides, and insecticides, which include a wide range of chemical compounds that impair or kill weeds, fungi, and insects, respectively.

Pesticides are sometimes referred to as *damage abatement inputs* (Lichtenberg1986). Damage abatement inputs reduce potential shortfall rather than further increase output (Lansink2008). This has analytical implications when measuring pesticides' contribution to yield, and in turn to food security. Namely, pesticides safeguard the *obtainable* yield which is determined by other environmental, agronomic, and economic factors (Licker et al. 2010). By safeguarding against down-ward yield risk, pesticides support yield stability.

Pesticides use intensity depends on many aspects, ranging from i) biological factors such as pest abundance, local climate, soil type, regional crop diversity, over ii) agronomic factors such as decisions on tillage, sowing date, variety susceptibility, fertilization, crop rotation, to iii) economic factors such as the expected yield and the on-farm economic and financial situation (Andert et al. 2015; Lechenet et al. 2016). The multitude of relevant factors results in a considerable spatial heterogeneity in pesticide use, even in geographically speaking small countries (Habran et al. 2022). Various studies have found sizable variability in pesticide use not only across different years and between different regions within a country, but also across farms that essentially faced the same environmental and socio-economic conditions (Andert et al. 2015; Lechenet et al. 2017; Nause et al. 2021), illustrating the importance of farmers' personal decision-making process. These studies also show the potential to reduce pesticide use.

Besides the pesticides' positive function as damage control agents, their use also leads to unintended consequences, so called externalities. The consequences for the environment and human health from misuse of these chemicals are of societal concern (Kohler et al. 2013, Edlinger et al. 2022). Pesticide residues are found in soils, surface water, groundwater, non-target plants, food and feed, animals and humans (Aktar et al. 2009, Popp et al. 2013, Sharma et al. 2019); pesticides can remain for years in the environment and accumulate in soils and water, but also in humans, albeit that in Europe of the levels of pesticide residues in food products beyond the legal limits are rare. Nevertheless, environmental and societal externalities may not be properly internalized into the product prices in the current markets (Popp et al. 2013), which leads to an excessive use, often going beyond not only the environmentally sustainable level, but also beyond the optimal level from an economic point of view. Various studies attempted to quantify the societal costs of pesticides. The adverse effects of pesticides on pollinators (Desneux et al. 2007; Johansen 1977; Sponsler et al. 2019) threaten ecosystem services with an estimated worth of hundreds of billions of dollars (Gallai et al. 2009; Losey & Vaughan 2006). Annual losses in developing countries due to effects of pesticides on non-target organisms were estimated at $8 billion (Aktar et al. 2009). In the United States, inadvertent resistance building in pests from pesticide applications was estimated to cost $10 billion per year (Sexton et al. 2007). For Europe, Fantke et al. (2012) estimated that the annual cost related to pesticide impacts on human health could reach 78 million Euros. However, only few countries have introduced taxes on pesticides.

In particular, some of these externalities also have direct impacts on farming activities which may lead to negative impacts on food security in the mid- to long-run. The impacts of pesticides on the flora and fauna are of particular relevance. A rich biodiversity is essential for natural pest control (Bonato et al. 2023, Gong et al. 2022). In other words, adverse effects of pesticides on biodiversity may reduce the natural pest control, which in turn leads to an elevated need for pesticides to manage plant health. This so-called *pesticide dependency* in agriculture is a complex challenge and often characterized as a treadmill (Hedlund et al. 2020). The degree of dependency is, among other factors, related to the bioclimatic conditions and the plant species cultivated (Popp et al. 2013). In addition, pesticide applications reduce the functioning of beneficial plant symbionts which has critical implications for the nutrient transfer to crops (Edlinger et al. 2022), and in turn yields. However, as of now these complex spill-over effects have been difficult to quantify analytically.

Moreover, there are some risks related to improper management of pesticides: as chemical pesticides are intrinsically toxic, errors during storage, application and disposal (of unused pesticides and pesticide packaging) can entail negative consequences for human health and the environment. While in the EU strict requirements on the use and handling of pesticides apply, impacts associated to improper management are particularly relevant in developing countries.

In view of these potential negative externalities, agricultural practices requiring smaller amounts of pesticides (or pesticides belonging to a lower risk category), such as organic farming and agro-ecology, are promoted in many countries. Integrated pest management (IPM) and in particular use of biological pest control are also binding requirements in the EU.

Current assessment – 2022-24

According to FAOstat, on average across 2015 to 2020 for total pesticide use China was leading and followed by the United States of America, Brazil, Argentina, Canada, Russia, France, Australia, India, and Italy. European Member States are ranked higher in terms of fungicide use.

An increase in transport costs and energy costs due to the Russian aggression in Ukraine may have resulted in modest increase of pesticides prices in the EU, but likely to a considerably lesser extent than for fertilisers. So far, it appears that a reduction of pesticide use, of a similar magnitude as the expected reduction of fertilisers use, for 2022/23 may not occur autonomously. Spikes in the energy and fuel prices may result in, for example, mechanical weeding being a less attractive alternative to herbicides, making crop protection via chemical tools more competitive. Further changes in climate may affect pesticide use. For example, droughts may lead to less pressure from fungal diseases and in turn need for fungicides. Extreme temperatures have been found to also lower insecticide applications (Möhring et al. 2022).

Forward looking – 2030

Broadly speaking, a consensus has been reached on the need to move away from pesticide-centric food systems, both in the public domain and in academia (Mustafa et al. 2021, Aktar et al. 2009, Sharma et al. 2019, Kohler et al. 2013). Arguably, a successful transition must build on the diversity of knowledge on complementary strategies for crop protection that is overarchingly formulated in the Integrated Pest Management principles. Such transition would minimize the negative impacts of pesticides on food security (i.e., supporting ecosystem services which may promote yields and resilience) and the environment, while assuring that pesticides' positive function (i.e., supporting yield stability through targeted applications and providing an emergency tool against severe pest and disease outbreaks) is not put at risk. In what follows, some agronomic and technological avenues will be sketched for sustainable crop protection practices that may redesign food systems going forward; this list is by no means exhaustive.

Integrated Pest Management (IPM) is a pest control strategy that synergistically integrates biological and chemical tools (Stern 1959). The EU Framework Sustainable Use of Pesticides Directive 2009/128/EC provides a modern definition of IPM by laying out eight general principles. Namely, (i) prevention and suppression, (ii) monitoring, (iii) decision-making, (iv) non-chemical methods, (v) pesticide selection, (vi) reduced pesticide use, (vii) anti-resistance strategies, and (viii) evaluation. Sound IPM is a knowledge-demanding and context-specific systems approach, which consequently utilizes a wide range of tools and technologies (Barzman et al. 2015). Hence, crop protection is more and more acknowledged to be more nuanced than an exclusive reliance on pesticides. The following three broad-picture developments may support various pillars of IPM.

Data and digitalization have the potential to reshape the agricultural sector in unprecedented ways (Rolandi et al. 2021, Mondejar et al. 202. Innovation addresses to a large extent crop protection, which can broadly be classified into tools that support i) the prediction of occurrence, ii) the detection of local severity, iii) the selection of tools, iv) the precise application, and v) the assessment of impacts (see OPTIMA H2020 project). An increasing interconnectedness of analytical insights ranging from soils ([75]), over crops (Acharya 2020, Shafi et al. 2019, Granwehr & Hofer 2020), to remote sensing based analyses of the environment and crop health (Hornero et al. 2020, Zarco-Tejada et al. 2018). Such advances in analytical capabilities will, and in part already do, enable spatio-temporal support in crop protection that improves the precision with which we may manage food systems. Such technologies allow for targeted, more nuanced, applications of pesticides (Zangina et al. 2021, Shafi et al. 2019, Mogili & Deepak 2018), or provide alternatives to pesticides altogether (Machleb et al. 2020, Xiong et al. 2017, Weis et al. 2008).

A sound integration of agro-ecological principles, both at field- and landscape-level, supports the prevention of pest and disease impact (Petit et al. 2020). On farm-level, various agronomic decisions may determine the resilience to pest and disease outbreak, and in turn the need (or lack thereof) of applying pesticides. Farmers generally practice a temporal rotation of crops. Similarly, improved spatial configurations (e.g., intercropping, strip-cropping) of hosts can enable natural pest control both at field- and landscape-level (Knipling 1980, Boudreau 2013, Ditzler et al. 2021, Juventia et al. 2021). Pest populations are spatial phenomena by nature (Turchin 2003). Consequently, Knipling (1980) introduced the idea of area-wide pest management via collective actions. More and more landscape-wide designs of crop protection are promoted in which total pesticide usage, as opposed to farm-level usage, is optimized (Topping et al. 2015, Epanchin-Niell et al. 2010). Just as temporal problems involve choosing a strategy that comprises a path of decisions which are interdependent across time (Fousekis & Stefanou 1996), optimal control in a spatial system involve simultaneously choosing actions across an interconnected landscape (Epanchin-Niell et al. 2012). Differences in the landscape configuration can also result in differences in the environmental burden from pesticide (Topping et al. 2015, Topping et al. 2016). A pivot to a more holistic landscape-perspective requires communication and coordination among decision makers, which is increasingly facilitated through better communication technologies (Tao et al. 2021, Dara 2019, El Bilali & Allahyari 2018,).

([75]) https://esdac.jrc.ec.europa.eu/resource-type/european-soil-database-soil-properties

Integrated Pest Management is centred around varieties with biotic resistances (Birch et al. 2011). In principle, resistance is defined as the reduction of the multiplication of the pest or pathogen whereas tolerance defines the degree of a loss, or lack thereof, of the plants' performance under pest or pathogen pressure (Ferrero et al. 2020). Plant breeding may broadly be described by three phases (Ceccarelli 2015). First, genetic variability is generated through crossing of available elite varieties, the introduction of exotic germplasm, the inducement of mutations, or by using genetic engineering techniques. Second, promising recombinants or mutants are selected and tested. Lastly, the variety is commercialized and, ideally, adopted by farmers. The difficulty of introducing a new trait, e.g. a resistance to a certain pathogen, into a marketable variety strongly depends on the heritability of the trait and the generation time of the plant species (Ceccarelli 2015). Also, the source of the genetic variability has considerable implications for the resources needed for selecting and testing the recombinants. Often, the main time- and resource-sink that breeders face is not the process of introducing the trait of interest but rather the procedure of removing undesirable genetic material that was inadvertently inherited during the crossing of parental lines (Tracy 2004). As the germplasm of wild species remains an invaluable source of biotic resistances and other agronomic traits (Nelson et al. 2018, Lee 1998, Tanksley & McCouch 1997), resources spent on removing genetic drag in conventional breeding programs are significant. *New Genomic Techniques* effectively prevent genetic drag. In turn, the development time and costs of new varieties is reduced and, more importantly, the technologies enable the introduction of multiple resistance genes into market-ready varieties in which quality traits of the original variety remain unchanged. Varieties with *stacked* resistances enable a system-wide rethinking of crop protection, which allows for significant reductions of pesticide use without affecting yields (Haverkort et al. 2016, Kessel et al. 2018).

International Dimension

As indicated above, in developed countries pesticide are currently key tools in managing pests and diseases. However, in less-developed regions the lack of access to pesticides is a known issue. Sheahan and Barett (2017), for example, estimate that only 16 % all cultivating households in a sample of 6 Sub-Saharan African countries applied agrochemicals to their fields. As phytosanitary concerns are a just cause for restricting international trade flows under the GATT, a collective approach to plant health is needed to prevent adverse consequences to regional development goals.

Interlinkage with other drivers

Pesticide use in crop protection is **not** an exogeneous driver of food security, but rather a socio-economic response to other drivers. Consequently, this driver is inherently, and deeply, interlinked with various other drivers for food security. In what follows, a selection of the most important interlinkages will be discussed.

Biodiversity loss is directly caused by pesticide use. A healthy flora and fauna support natural pest control, pollination, nutrient uptake, among other factors. In turn, biodiversity is critical for food security, which implies that the adverse effects of pesticide on it have repercussions for food security in the mid- to long-term. Conversely, biodiverse agricultural systems embracing a number of good agricultural practice (enhanced crop rotation, landscape features, etc.) are more resilient to pests than conventional high-intensity systems.

Climate change causes unprecedented risks to crop production across the globe. A changing climate may result in an increased fragility of landscapes in which pest and disease impacts are more pronounced. Simultaneously, a changing climate may shift pest and disease habitats and results in EU agricultural land being susceptible to novel risks. Increased precipitation events may elevate the risk for fungal diseases causing an elevated need for fungicides, whereas droughts may have the opposite effect on fungicides and insecticides.

Pests and diseases pose significant risks to the agricultural sector. Climate change shifts pest and disease habitats, and international trade transports organisms across the globe. Introductions of new pests can affect crop production and necessitate response, among other aspects through pesticide use.

Environmental pollution may indirectly affect natural pest control and crops' resilience to pest and disease impact. Simultaneously, pesticides are among the pollutants and in turn adversely affect soil-, field-margin-, and water-organisms, thereby contributing to environmental degradation and ecosystem service losses which may lead to mid- to long-term repercussions for food security.

Soil health is an essential pillar for sustainable agriculture. The relationship between soil health and pesticides is complex. On the one hand, no-tilling systems promote soil health and are often supported by herbicide use. On the other hand, e.g., fungicides can adversely affect (beneficial) soil organisms.

Investment in R&D is an important driver in the domain of crop protection. Technological solutions range from sensor-based precision agriculture, satellite-based remote sensing, over the development of biocontrol methods, to improved plant breeding with New Genomic Techniques. In addition, R&D promoting low intensity solutions, such as nature-based agriculture, agro-ecology, organic farming, etc. can enhance natural protection of crops while increasing their productivity.

Fertiliser and pesticide use have complex interdependencies. A higher fertiliser uses in some crops results in a greening of the plant that can attract pests, in turn demanding higher pesticide use. Conversely, nutrient deficiencies lower the general resilience of the plant which may affect the impacts under varying levels of pest or disease pressure. Lastly, pesticide use affects soil symbionts which support nutrient uptake and in turn lowers the efficacy of fertilization

Intensity of production may influence the level of natural pest control, the attractiveness of fields for pests, and the economic risk of pest and disease outbreaks. Complex spatial configurations of hosts, e.g., intercropping or strip-cropping, may require less pesticide use but complicate agricultural intensification as these designs may limit the scalability of equipment and processes. In addition, promoting biodiversity-friendly practices enhances natural pest control on agricultural areas.

8.13. Availability of workers

General context and what is at stake?

The presence and availability of the needed workers along the agricultural value chain has a direct im-pact on the capacity of the sector to supply the EU market with food. A shortage of labour in agriculture during the growing season can lead to lower quality and/or quantity output and to a higher use of chemical products. A persistent labour shortage may lead firms to gradually substitute labour with physical capital (e.g. mechanization, robotics) (Astrov et al. 2021; Mitaritonna and Ragot 2020).

In the EU, there is a serious risk of a shortage of agricultural seasonal workers who usually come from other places than where they are employed (including from non EU countries), potentially preventing that crops will not be properly attended or even harvested. This risked happening during the COVID-19 pandemic when the mobility of workers was hampered. A risk exists in particular for Germany, Italy, Spain, France and Poland, where high numbers of migrant seasonal farm workers are implied (Europe-an Parliament, 2021). Slaughterhouses' operations were also heavily disturbed during COVID-19 by lack of available workers. The war in Ukraine also made unavailable number of workers involved normally in agriculture, food processing and transport.

This seasonal shortage problem comes on top of the structural issue of shortage of suitable labour in agriculture that in some Member States is getting more pronounced every year. In fact, the EU27 agri-cultural workforce has been reduced by at least 2 million workers over the last decade. The shortage of workforce also affects skilled workers, which are more likely to work in non-agriculture sectors (Eu-rofound et al., 2021; Schuh et al., 2019). The depopulation of rural areas, the working conditions, the lower attractiveness as compared to other sectors, and missing training opportunities are the main factors behind the shortage of skilled labour.

A large share of workers is of foreign origin (both intra-EU and extra-EU) and their availability depends on the conditions of migration in the different Member States. Intra-EU and extra-EU migrant workers exert a positive impact on agricultural sector competitiveness and represent a solution for the structural shortages of labour in the farm sector (ESPON 2017, CREA 2019, Forget et al. 2019, European Parliament 2021, Antonioli et al. 2022). However, migrant seasonal workers usually perform occupations avoided by local workers because of the poor working conditions (European Parliament, 2021). It is estimated that the number of intra-EU and extra-EU migrant workers increased from 4.3% of the total agricultural workforce in 2011 to 6.5% in 2017, which partially offset the downward trend in local workers. This represents a growth of 1.4 million migrant workers, of which 585,000 come from EU Member States and around 837,000 come from non-EU countries.

Given the above, it is important to analyse the regional dimension of agricultural employment. In 2019, the sector provided around 11.3% of total employment in less-developed regions. Despite the relevance of agriculture in terms of employment, the less developed regions registered most of the de-cline in the agricultural workforce (in 2008, agriculture had a share of 17.8% in total employment in these regions). The average agricultural workforce in the EU fell from 6.2% to 4.2% in the same peri-od.

Current assessment – 2022-24

The war in Ukraine is causing a shortage of seasonal labour and complicating the harvest, tending and planting operations, especially in the fruit and vegetable sector. Tensions are also noted in transport and logistics as well as food industry. A number of Ukrainian workers usually employed in the EU are staying in their country to deal with the conflict and its impact on their families.

There is also a particular concern for fishing crews as some vessels have been lying idle due to the steep increase of fuel prices, and crews may be progressively leaving the sector, which could lead to a structural decrease of the EU supply. However, this reduction in the supply due to lack of workforce may be rather limited as more than 90% of the crew in the EU fishing fleet are nationals from the same country the vessel is located STECF (2022a) and there is already overcapacity in the EU fishing fleet. While the majority (82%) of people employed in the EU aquaculture sector were nationals of their own country, while 3% were from non-EU/EEA countries (STECF 2022b).

Streamlining existing hiring procedures, actively supporting farmers in fulfilling labour legal criteria and opening up new legal pathways for seasonal migration would help in satisfying the demand for extra-EU workers, which will partially help to address the labour shortages in the sector.

Forward looking – 2030

The downward trend in the agricultural workforce is expected to continue until 2030 in most of the EU Member States, also due to the ageing trend in the agricultural workforce. In contrast, the food and beverage industry's workforce shows less negative forecasts .

Food chain operators will need to find solution to address future labour and skills shortages by increasing attractiveness of offered jobs and through deployment of technology. Technology and automation (e.g. through digitizing workflows, automation of repetitive tasks) may increase the attractiveness of work in the food sector by offering higher skilled jobs. Governments may alleviate the labour shortage problems in the food sector through adopted regulations (e.g. amendment of labour laws reflecting the specific needs of food sector, regulation of seasonal migrant workers, regularising extra-EU irregular migrants) or support programmes (e.g. for educational and vocational training to improve the knowledge and skills of workers) (Mitaritonna and Ragot 2020).

International dimension

Shortage of non-EU workforce may affect EU food security by reducing food production of EU based firms more dependent on foreign labour. For example, according to Eurostat the share of non-EU citizens employed in agriculture was 3.7% of total employed aged 20-64 in 2019 (compared with 4.6% over total employment). There are substantial differences among EU Member States. This figure was 18.9% in Cyprus, 14.7% in Spain, 12.2% in Italy, 5.8% in Greece, and 4.4% in Denmark.

Immigrants generally play a crucial role in supporting agriculture and rural areas in developed destination countries. As pointed out in (FAO 2018), many developed countries that experience rural depopulation, international migrants can contribute to filling labour shortages in agriculture. In the US, for ex-ample, about 75% of all hired workers in high-value crop production were born outside the country (US Department of Labor, 2016). Seasonal migration of agricultural workers is also not uncommon in developing countries, and in Africa this may also be across borders (FAO 2018). However, migrants often face poor working conditions and a lack of labour rights protection and need to be improved in many developed and developing countries (FAO 2018).

Interlinkages with other drivers

Availability of workers has a direct positive impact on supply chain efficiency, farm income and food prices. It may also play a positive role in the decision of the younger generation to set up their own farm (generational renewal). Conversely, a shortage in workforce and skills may affect agricultural practices and favour the adoption of less intensive human workforce practices (i.e., extensive farming, mechanization and/or automation of specific practices), which could also interact with the impact of investments in R&D. The driver availability of workers is specifically affected itself by demographic trends and conflicts.

8.14. Agricultural and consumer food prices

General context and what is at stake?

The impact of food price increases on food security will differ depending on the stages of the supply chain where prices increase and to what extent these price increases are passed through to consumers. Heightened prices for inputs, such as fertilisers and fossil energy, can cause production challenges for the whole food chain. If the significantly higher production costs at farm level are not compensated by higher farm output prices, this will affect the profitability of farms and farm income, which can ultimately affect supply and thus food availability. On the other hand, increasing farm gate prices may actually raise the returns to farming and boost food production and food availability. Consumer food prices are a crucial driver of food security, as they determine the quantity and quality of food that households and individuals can acquire or access. In addition, food inflation can fuel overall inflation and decrease disposable income, thereby further deteriorating economic access to food.

When faced with higher consumer food prices, especially poor households, who spend a large share of their budget on food, will have to resort to coping strategies. These may involve substitutions towards more calorie-dense but micronutrient-poor and less diverse foods. This can compromise diet quality and aggravate problems of overweight and micronutrient deficiencies and thus lead to an increase in non-communicable diseases.

Current assessment – 2022-24

While already high in the wake of supply disruptions related to transport and logistics bottlenecks and the surge in global demand during the recovery from the COVID-19 pandemic, Russia's war on Ukraine provoked a further surge in agricultural commodity prices. Disruptions of trade in and production of certain commodities for which Russia and Ukraine are important global suppliers (cereals, oilseeds, vegetable oils) and further surge of energy and fertiliser prices caused additional upward pressures on already high food prices.

FAO's international food price index climbed to its all-time high in mid-May 2022. At this point, for ex-ample wheat prices were up by 32% compared to their level at the start of the war in Ukraine. Commodity prices for most foods have fallen back to pre-war levels. Notwithstanding, compared to historical standard, food prices remain high (FAO price index of October).

While commodity prices have fallen, consumer prices continue to rise. According to data from the Eurostat (2022) Harmonised Index of Consumer Prices (HICP) for October 2022, food inflation in the EU amounted to 18 % compared to 11.5% for the headline inflation. Most Member States have been experiencing double digit-inflation at multi-decade highs. The largest increases are seen for oils and fats (+32.5%) with prices driven upwards by the lack of supply of sunflower oil from Ukraine and propagated to other direct substitutes. However, important price increases are also seen for foods like bread (+19,8%), milk, cheese and eggs (+23,8%), and vegetables (+20,2%).

The impact of these food price increases on economic access to food will in part be determined by the proportion of households' budget or disposable income that is usually spent on food. On average, around 13% of EU household consumption expenditures in 2019 was allocated to food and beverages. There is, however, considerable heterogeneity between and within countries (Eurostat 2020) putting food security at risk for low-income households, which allocate considerable amounts of their budget to food.

Forward looking – 2030

Social protection measures and safety nets are key to insulate vulnerable populations, who spend large shares of their budgets on food, from the worst impacts of food inflation. While many countries have put in place social protection schemes in response so soaring prices of food, most seem to be implementing short-term subsidy programmes rather than more general safety nets that would be ready to respond to future food price shocks (Gentilini et al. 2022).

International dimension

By July 2022, consumers in a majority of both high- and low-income countries faced food price increases of between 10% and 30%—or even more.

While high food prices are often perceived as an unequivocal threat to global food security, it is important to point out that the reality is more complex (Swinnen and Squicciarini 2012). Food production is an important source of income for many of the world's most food insecure populations. For households that are net sellers of food, the positive effect of food price increases on farm gate prices and income may outweigh the negative effect on the increased cost of purchased food. On the contrary, the negative impact of food inflation for net consumers of food, and the urban poor in particular, is likely to be particularly large. The same holds at the macro-level (Swinnen 2011). Self-reported food security in Africa, for example, improved for net food producers over the period 2005–2008, when global food prices increased dramatically. This was observed both at the micro-level, among rural households, and macro-level, among net food exporting countries (Verpoorten et al. 2013). However, most developing countries are net food importers (Valdés and Foster 2012) and the urban poor and a large share of rural poor people in developing countries are net food buyers with a high share of food expenditure and rather inelastic food demand (Compton et al. 2010, Dorward 2012), which makes them particularly vulnerable to food price inflation and its adverse effects on access to nutritious food (Brinkmann et al. 2010, Christian 2010). Regions in which a large share of poor people live in urban are-as (such as Latin America and the Caribbean and Europe and Central Asia) are therefore likely to be more adversely affected by rising food prices (World Bank, 2022).

In addition to the distribution of net sellers and net buyers of food, the impact of food inflation on food security also depends on the rate at which global prices are passed on through local prices. Especially for lower-income countries, there is wide variation in the pass-through of prices from the world market (Ivanic et al. 2012).

Interlinkages with other drivers

As the balance between food supply and food demand determines food prices, all drivers that affect food production (e.g. biophysical and environmental drivers, fertiliser and energy prices) and trade can be linked to prices. These relations are bidirectional. Higher food prices can, for example, impact countries' competitiveness on the world market if the increase of prices is asymmetric. Food prices will also affect the relative profitability of competing land uses. The relation between food prices and farm income is complex. Higher food prices could improve farmers' income (particularly those who are net sellers) but might also affect prices of inputs and the net effect is very specific to the farm level situation. Similarly, drivers that affect food choices will also influence prices. Yet, at the same time food prices will shape food choices. It is worth noting that food price rises have been associated with in-creases in social unrest (e.g. Bellemare 2019).

8.15. Farm income

General context and what is at stake?

Farm income determines the supply response of farmers in the short-term and the long-term. Lower incomes will translate into reduced capacity to purchase inputs in the short-term. As such, farm income affects choices in terms of activity, including for example turning towards less agrochemical input-intensive crops (Di Corato and Zormpas 2022), the use of inputs, and agricultural practices. In some cases, this can lead to lower and more variable yields and overall production, thus negatively affecting food availability.

In the longer run, lower farm income can also reduce farmers' ability to invest and therefore to ensure future productivity gains and future increase in farm income (Sckokai and Moro 2009). More generally, a reduction of farm income will influence farm viability, with an increased risk of farms halting their activities. This poses risks for the stability of food supply and food availability.

Current assessment – 2022-24

Farmers' income is expected to be significantly impacted by the current surge in input prices. Taking into account expected impacts of the Russian invasion of Ukraine, the 2022 Medium Term Outlook estimates that energy and fertiliser costs have increased by 45 %. The increase in agricultural prices may contribute to cushion the impact, in particular in the arable crop sector, and for farmers who either sell on future markets or can store part of their production to sell it physically when prices are at their highest (usually outside of the harvest time).

The EU fishing fleet landed about 3.9 million tonnes of seafood with a value of EUR 5.8 billion in 2020 (STECF, 2022). There has been a reduction in the supply and income from marine fishing since 2016-17. This reduction is largely driven by the efforts to reduce overexploitation (i.e., by reducing the fishing quotas) and external factors that have undermined the performance of the EU fishing fleet, such as Brexit, the impact of the COVID-19 pandemic and more recently, high fuel prices.

However, the economic performance and overall viability of the sector, remains still very dependent on the fuel prices paid by the fisheries sector. Estimates suggest that on average, fuel prices above €1.0-1.1 per litre threat the short-term viability of the EU fishing sector; while the long-term viability would be at stake when fuel prices are above €0.6-0.7 per litre (Guillen et al. In press).

Forward looking – 2030

In the medium- and long-term, farmers and fishers' income may be expected to remain under pressure due to relatively high energy and input prices, and the impact of climate change on yields and animal production (due to higher risks of animal diseases).

International dimension

Globally, the majority of the food insecure population resides in rural areas and depends on farming for most of their income. This is especially true in Africa. This implies that farm income is therefore a crucial determinant of their access to food and food security as even smallholders and subsistence farmers often rely on food purchases for a substantial part of their food consumption (Sibhatu and Qaim, 2017). Consumption of self-produced crops did not cover consumption needs for 80% of farm households in 17 countries of sub-Saharan Africa (Frelat et al, 2016).

Farmer income is impacted in a very different manner by the current surge in input and output prices across the world. It depends on the level of use of input (notably energy and fertiliser), the specialization and the degree of exposure of their local or national market to international price changes. While incomes of modern, intensive farmers located in open economies will be highly exposed to changes of prices (input but also output), smallholder farmers in developing countries, characterised by low-input farming systems selling on local markets may experience less changes in their incomes as a result of current price hikes.

Interlinkages with other drivers

Farm income is intrinsically linked to many other drivers of food security. Farm revenues are a function of food prices and food production on the farm and will therefore be affected by all drivers that interact with food production including for example climate change, plant pests and diseases, and soil health. The direction of the effect of these drivers that affect production is not always clear. Considering the very inelastic demand for some food products, negative effects on food production can translate into higher prices. This can offset the income effect of decreased production.

Farm income is of course also determined by costs. Higher prices for inputs (including energy and fertiliser prices) will increase costs thereby reducing farm income. Integrating energy efficiency measures in farm management as well as renewable energy solutions in rural landscape could be engaged as mid-term and long-term solutions for stabilising and/or increasing farm income, whereas reducing the carbon footprint of the food production. The availability of workers can also affect farm income through its effect on labour cost. On-farm post-harvest food loss will also lead to a reduction in farm income.

The relation between farm income and investments in R&D is bidirectional. Increased farm income can lead to more investments in R&D. At the same time, these investments can contribute to cost-saving or revenue-increasing technologies that positively affect farm incomes.

8.16. Access to finance

General context and what is at stake?

The EU is the largest agricultural producer in the world but investments in the sector are overall on a decreasing trend. In the last few years, and mostly due to the Covid-19 health crisis, farmers' investment behaviour was halted across the EU and their attention shifted towards working capital finance as it helped overcome delays in payments and supplies, or survive. This was further stimulated by the emerged energy crisis in 2022 due to which input prices and inflation rose, and the pressure on farms' incomes became significant.

In the EU, the agriculture sector often faces higher interest rates offered by banks alongside unfavourable conditions, than other economic sectors. In this context, European Commission survey done via fi-compass ([76]) found that half of the farmers applying for long-term loans must provide a guarantee with a higher level required by banks than for other economic sectors. The

([76]) Technical assistance platform 'fi-compass' for financial instruments under shared management. See The European Agricultural Fund for Rural Development | fi-compass general characteristics of the sector (e.g. seasonality) with low and fluctuating profit margins and cash flow (especially for smaller farms), combined with the risks intrinsic to agriculture production as well as the increasing negative impacts caused by climate events such as droughts, floods, fires, etc. lead banks to be much more hesitant in financing agriculture at normal terms.

A financing gap for the agriculture sector has been estimated by 2020 Fi-compass report ([77]) to be in the order of EUR 19.8 to EUR 46.6 billion for the EU24. Small-sized farms, young farmers, new entrants, and innovative investments find it harder to access financing. Almost two thirds of the gap is due to difficulties in accessing long-term loans. Similar results are also found by a number of ex-ante assessments carried out by EAFRD managing authorities in the context of the setting-up of new financial instruments under the CAP Strategic Plans ([78]).

Farmers face more difficulties in accessing finance than SMEs from other economic sectors. Member States with particularly high rejection rates for farmers also have the highest rejection rates for SMEs from other economic sectors. At the same time, access to finance at EU level, especially bank loans, is estimated by Fi Compass critical for 12.2% of all farmers using them for investment finance and 10.4% for working capital with important differences between Member States.

According to the same source, in 2018, the agricultural sector in the EU24 invested EUR 54.1 billion in fixed assets, a decrease of 4% compared to year 2011.

Current assessment – 2022-24

The transformation from labour-intensive to capital-intensive agriculture is still ongoing in many countries, as observed for example in Poland, Croatia, Lithuania, Hungary and Portugal. In many Member States, the larger-sized farm segment is investing in modern technology, while for most farms, who are small-sized and often lack modern equipment, productivity has not reached its full potential. In the transition towards sustainable and/or green agriculture, access to funds is a key factor for farmers to be able to invest in new and more sustainable and climate-neutral practices.

Support from the CAP – mainly direct payments, investments, and start-up support – facilitates farmers' access to lending by improving their cash flow and loan repayment capacities. However, it is insufficient as budgets are rather low. Financial instruments help reduce that gap, but more financing is needed to the very high financial needs for transforming and stabilising the sector.

The negative impacts from the 2022 energy crisis and the war in Ukraine may continue further to disrupt the investment behaviour of farmers and their profitability thus creating further complexities in their access to financing from the financial market. In the meantime, the European Central Bank continues to increase the main interest rate, which makes banks' financing for farmers even more expensive and more difficult to afford.

([77]) Published in November 2020. New farm survey is ongoing with new results expected by mid-2023. See also: Financial needs in the agriculture and agri-food sectors in the European Union (fi-compass.eu)

([78]) Data available in the CAP Strategic Plans for Slovakia, Greece, Spain, Bulgaria, The Baltic countries, Poland, France, etc. Some recent presentations are to be available here: Towards a more resilient and sustainable agriculture sector – 8th annual EU conference on EAFRD financial instruments | fi-compass

Forward looking – 2030

In addition to investments to improve productivity, climate change adaptation will require farmers to spend significant financial resources in the near future to remain part of the green and digital transitions, and to contribute to the objectives of the CAP and the European Green Deal. Support for green investments is expected to increase, and so the demand for financing new technologies and assets fitting into this concept.

Fi compass analysis showed, however, that obtaining financing for investments related to climate change adaptation poses difficulties for farmers, as it is sometimes difficult to prove that these investments will render higher profit margins whereby banks are hesitant to lend for this purpose. The lack of specialised in agriculture financing banks in many countries, or the significant concentration of that financing into just one or few banks, leads to further complications and oligopolistic market behaviour that prevents farmers from accessing budgets allowing them to show their full business and societal potential.

International dimension

It is with no doubt that any positive investment change in EU agriculture leads to a positive spill-over effect on the international stage. The EU, being one of the main world exporters of quality food, can further increase its international role when internal market changes are diminished and positive economic trends are observed.

Interlinkages with other drivers

The CAP financing is not the only budget providing farmers with possibilities to overcome hurdles and to invest. Other sources also play a role, such as the European Investment Bank (EIB) Group and other financial institutions.

8.17. Household income

General context and what is at stake?

In combination with food prices, household resources and household income determine economic access to food. Household income impacts both the quantity and quality of food that can be purchased. As income rises, the proportion of income spent on food tends to decline, even if total food expenditures keep rising. Additional income does not only increase the amount spent on food, but also positively affects dietary diversity (e.g. Clements, 2018). Typically, consumption of "higher valued" food is expected to increase with income, whereas "staples" will be consumed less. Higher income levels do not guarantee healthy diets. On the contrary, calorie overconsumption and consumption of several unhealthy foods appears to increase with income (e.g. Colen et al., 2018; Global Diet Quality Project, 2022).

At the same time, within high-income countries such as EU Member States, those with limited means often consume cheaper energy dense and nutrient-poor diets, resulting in both micronutrient deficiencies and overweight (Darmon and Drenowski, 2008).

The stability of access to food is also likely to be a function of household income as food price shocks and other shocks have greater adverse effects on households at the bottom of the income distribution (who usually spend a large share of their income on food).

Current assessment – 2022-24

In 2021, an estimated 74 million people or 16.8 % of the population in the EU were at risk of poverty with an income below 60% of the national median (Eurostat, 2022). These households are likely to spend a considerable share of their income on food and be particularly vulnerable to the effects of current food price increases. The proportion of the EU population at risk of poverty increased slightly between 2020 and 2021, with notable increases in some Member States that already had higher rates of poverty.

The EU is experiencing a rapid increase in inflation rates fuelled by high energy prices and the war in Ukraine. This implies that real incomes and purchasing power are under pressure, undermining food security in Europe. It is essential to pay particular attention to vulnerable households which, without alleviating measures, could face reduction in the quantity and quality of food they consume. In the short-term, targeted social protection measures can help vulnerable low-income households cope with shocks.

Forward looking – 2030

In the longer-term, it is essential to target root causes of poverty and social exclusion as this is our best lifeline against the adverse effects of high food prices on food affordability.

International dimension

COVID-19 marked the end of a phase of global progress in poverty reduction. While there were signs of (slow) recovery, rising inflation and the effects of the war in Ukraine are expected to exacerbate the situation further. Compared to pre-pandemic projections, these combined crises are estimated to add an additional 75 million to 95 million people living in extreme poverty in 2022 (Mahler et al., 2022). The increase in global poverty was concentrated in South Asia, followed by sub-Saharan Africa, the region with the highest poverty rates. While governments can mitigate the negative impacts on income and food security through social protection policies, in many countries governments' finances have been depleted by the various fiscal measures enacted through the COVID-19 crisis.

While most of the poor around the world can afford an energy sufficient diet, they cannot afford either a nutrient adequate or a healthy diet (FAO, 2020). An estimated 3 billion people could not afford a healthy diet in 2019 (FAO, 2022). In 2020, the measures put in place to contain COVID-19 sent the world and most countries into economic recession, with per capita incomes contracting in more countries than at any time in the recent past. Data is not yet available to estimate how the resulting changes in income distributions affect the number of people who cannot afford a healthy diet, but it is clear that this number will have increased.

In the long run, income growth in developing countries is projected to increase food consumption and lead to more diverse diets. Yet, income growth is also associated with excessive intakes of fats and sugars (e.g. Colen et al., 2018).

Interlinkages with other drivers

Economic access to food is determined by the interplay between household income and food prices. While not necessarily leading to healthier diets, income shapes food choices. Globally, 81 percent of people living in extreme poverty live in rural areas and depend on farming for most of their income (World Bank, 2022). As such, the distinction between farm income and household income is much less clear. This also implies that for some of these households, increasing food prices may increase income, thereby offsetting the negative effect of the increased cost of purchased food. In general, households with lower incomes are more exposed and more vulnerable to shocks. This includes food or energy price increases, but also extreme events from climate change.

8.18. Competing land and crop uses

General context and what is at stake?

Land is a finite and scarce natural resource that is subject to many competing claims (Muscat et al. 2020). Land is also an integral part of ecosystems and indispensable for biodiversity and ecosystem services (IPCC 2019). The European Union comprises 410 million hectares of land (Eurostat 2018). Woodland covers the largest share at about 41.1%, nearly a quarter is covered by cropland 24.2%, and grassland accounts for 17.4%. Artificial and built-up land amounts to 4.2%.

Climate, economic and policy-driven land use change can result in land transformations and competition for land for different uses. In the EU, despite a reduction in the last decade, land take related to the expansion of built-up areas, which mostly affected agricultural areas, amounted to 539 km2/year between 2012 and 2018. Between, 2000 and 2018, an estimated 0.6% of arable land was lost. Urban sprawl converted 0.5% of pastures and mosaic farmlands and 0.3% of grasslands into artificial surfaces (EEA 2021). The main drivers of land take during this period were industrial and commercial land use as well as extension of residential areas and construction sites. 78% of land take between 2000 and 2018 affected agricultural areas, i.e. arable lands and pastures, and mosaic farmlands.

Agricultural land is allocated across different uses and objectives including animal rearing or the production of different crops for food or industrial use, animal feed, or biofuels. These land-use choices are shaped by policy incentives and demand for different products and services.

Agricultural area may not be a constraint at EU level by itself. Whether it is a constraint or how it may trigger land use change elsewhere also strongly depends on how crops produced are subsequently used for either food, materials, feed, or fuel.

Evolving demands for use of crops in the bioeconomy will in turn affect land use decisions on agricultural land and beyond. These processes have increased the complexity of the agricultural market itself but have also increased the interconnection and dependencies on non-agricultural markets (e.g. energy).

In the EU, about 55% of cereals are used for feed (about 30% of wheat is used for feed). While the availability of oilseed meal feed has increased with the growth of the EU rapeseed acreage due to biodiesel demands, the EU imports about 20-25% of feed protein needs, especially from soy beans and meals.

Decreasing EU feed imports could lead to decreased cropland demand in the exporting countries. However, if decreasing the EU feed imports implies an increased EU production of feed crops, this would also lead to less EU production and exports of food crops (Henseler et al. 2013, Karlsson et al. 2021), with potentially adverse impacts on global food security. This strongly depends on the associated modifications of the food value chain and feedback within the global food system.

In Europe, the share of arable land devoted to biofuels is limited to about 7% (4 % of cereals). However, the EU policy on biofuels was an incentive to increase the production of rapeseed in the EU (+79% in volume and +46% in area, in 2020 compared to 2003). About 70% of the rapeseed oil is used to produce biodiesel. However, the increase of rapeseed cultivation is also contributing to reducing the EU dependency on feed imports. This is because the main by-product of biofuels is oilseed meal which is an important source of protein, in particular for monogastric livestock (pigs and poultry).

Nevertheless, despite a wide range of estimates quantifying the extent of the impacts of biofuels on food security, there is a consensus in the literature that the food versus fuel trade-off is created by biofuel production from food crops, and that continued expansion of biofuel production increases pressure on global food security (Rosegrant and Msangi 2014). Accordingly, a majority of studies underline prioritising the use of land resources and biomass for the use of human food before its use as feed or bioenergy (Muscat et al. 2020). Being aware of such trade-offs, the EU has provided an improved framework for biofuels for transport, and biomass for bioenergy in general, by introducing sustainability criteria and minimum greenhouse gas savings, with the update of Annexes to closely monitor dynamics on the global markets, such as high indirect land use feedstock that become ineligible for achieving the binding Union's target for renewable energy sources.

Globally, there is a long-term trend for increased demand for maize and soybeans for biofuel production – especially in the USA, increasing amounts of those crops are used for biofuels. Therefore, further restrictions towards the use of land for biofuels production may also be necessary in other countries in order to limit policy-induced biofuels pressure on global food security.

Biomass is foreseen to become increasingly important as a resource in the EU (Muscat et al. 2021), also considering renewable energy objectives. Currently in the EU, land-based systems produce roughly 1 billion tonnes of dry matter of biomass in the EU per year, of which 50% of this total amount in dry matter corresponds to crops. These are grown on roughly 36% of the total EU-27+UK territory (2018 EEA extent accounts). Depending on where the biomass will be produced, either direct or indirect land use change will occur and ultimately compete for food-growing areas.

Land is an integral part of ecosystems and indispensable for biodiversity and ecosystem services (IPCC 2019; IPBES 2018). Ecosystem services range from the biomass provision (e.g. crop, timber and fisheries) to the filtration of pollutants (from air, water and soil) to the protection from natural hazards (e.g. flooding and landslides) and maintenance of habitats directly and indirectly used and valued by people (e.g. pollination, pest control and carbon sequestration).

Agroecosystems in good condition are able to provide higher flows and more services than fragmented and degraded agroecosystems. Thus the management of food-producing land affects not only the food production itself, but a range of ecosystem services (Liquete et al. 2022).

Current assessment – 2022-24

Global market price developments and constraints in land availability within the EU can lead to an expansion of EU imports from third country markets as a means to complement domestic supply with consequent land use change impacts outside of the EU.

In the medium term, biofuel demand will decrease following trends in road transport fuel use, partly mitigated by increasing blending rates. ILUC certification for biodiesel is expected to create challenges to palm oil, leading to lower imports. Ethanol production is projected to slightly decline in the medium term, while the production of advanced biofuels is due to increase, favoured by double counting towards blending mandates.

Regarding feed, the progressive specialisation of livestock and crop production in the EU has led to the shortening of crop rotations around cereals and oilseed crops, especially rapeseed. The EU currently needs to import around 20-25% of its feed protein needs, mainly in the form of soya beans and meals. Soybean trade is an important driver of land-use change and particularly associated with agricultural expansion and deforestation in South America (Gaspari et al. 2013, Fehlenberg et al. 2017). Choices for feed sources may be altered. A proposed option to decrease EU soybean imports is using more grass–legume silage instead of maize silage, as this would increase on-farm protein production and help reducing the dependency on soybean imports (Lüscher et al. 2014).

Competing demands on land in the EU became apparent when in 2022 a one-year derogation from certain Good Agricultural and Environmental Conditions (GAEC) including set-aside was adopted with the aim to promote food security (following the war of Russia on the Ukraine). The derogation allows exemptions in relation to fallow land, maintenance of non-productive elements on arable land, and crop rotation requirements. .

Forward looking – 2030

A framework that is often used to assess how different land management strategies impact biodiversity and agricultural production is land sharing and land sparing. Is biodiversity better off in landscapes where intensive agriculture is concentrated and land for nature is available elsewhere? Or do mosaic landscapes composed of low-intensity agriculture intersected by natural elements provide a better biodiversity friendly matrix? Obviously, how this debate plays out is strongly species, context and scale dependent with diverging outcomes when considering landscape to international dimensions. In addition, recent research also points out that land-sparing and sharing can have complementary benefits for conserving biodiversity (Valente et al. 2022).

Allocating and prioritizing land use is also strongly related to the intensity of production and how this is embedded in the landscape. Environmental pressures may manifest as land use change. Land management practices and the resulting intensity of land use needs explicit consideration (Levers et al 2016).

The potential impact of land-related emission mitigation strategies on food security, in particular due to food price increases, is outlined in several quantitative studies (Fujimori et al. 2022). This underlines the need for monitoring and coordination in emissions reduction and agricultural market management policies to avoid adverse effects on food security.

Modification of the food value chain also interlinks with behavioural and social change. As consumers increasingly opt for more sustainably produced food and healthy, more plant-based diets, the development of sustainable livestock production to meet consumer demand while reducing the environmental and climate impact of animal production is crucial.

International dimension

The interrelations between the different uses of land in the EU and globally are manifold, and so are their potential impacts on food security.

Globally, agricultural land area amounts to five billion hectares, or 38 percent of the global land surface. About one-third of this is used as cropland, while the remaining two-thirds consist of meadows and pastures for grazing livestock. In terms of per capita availability, cropland area per capita between 2007-2016 was smallest in Asia (0.13 hectares per capita), followed by Africa (0.22 hectares per capita), the Americas and Europe (0.40 hectares per capita), and Oceania (1.21 hectares per capita) (FAO, 2020).

Winkler et al (2021) estimated that land use change has affected roughly 32% of the global land area between 1960 and 2019 and identified that afforestation and cropland abandonment are more prevalent in the Global North and deforestation and agricultural expansion in the South. The main driver of global trends in land use change are attributed to the effects of global trade on agricultural production (Winkler et al. 2021).

Increasing global demands (e.g. China) to sustain increasing livestock population are shifting international demand patterns, notably for soybean. Brazil has stepped in as the major supplier to international soybeans market replacing the US with attendant impacts on forest protection.

Searchinger et al. (2022) estimated that Europe's agricultural footprint includes 24 million hectares of foreign land used to supply net agricultural imports, contributing to global deforestation.

Globally, livestock annually consumes about 6 billion tonnes of feed (dry matter). While this includes about 30% of global cereals production, 86% of it consists of materials that are not eaten by humans. In other words, only 14% of dry matter ingested by livestock is edible to humans. About 72% of the global livestock grain intake is consumed by monogastric animals (e.g. pigs and poultry), whereas more than 57% of the ruminants' consumption is based on grass and leaves (Mottet et al. 2017, FAO 2022).

Moreover, globally large areas of land are not suitable for the production of crops for human consumption, whereas forages are converted by ruminant animals into meat and milk products, often under extensive grazing systems (Herrero et al. 2013). Accordingly, at global level, the share of food-competing feedstuff (in quantities of dry matter) for cattle and dairy is calculated to be 3-4%, which is much lower than for poultry (68%) and pork (38%) production (Sandström et al. 2022). However, differences in the shares of food-competing feed hide big differences across production systems and countries and range from between 4% in Africa, 15% in Europe, to about 20% in North America. Moreover, diets in intensive beef cattle systems in North America and Europe can consist of more than 70% food-competing feedstuff (Sandström et al. 2022), but such production systems are also characterised by lower feed conversion ratios and hence lower total feed consumption (Herrero et al. 2013).

At global level, and specifically for developing countries, small increases in efficiency in livestock production, i.e. focusing on improvements in feed conversion ratios, can prevent further expansion of and even reduce arable land dedicated to feed production (Mottet et al. 2017, Herrero et al. 2016). In addition, feed components that do not compete with human food consumption such as surplus food and by-products authorised for feed or industrial biomass streams can provide a viable complement to strategies that increase production efficiencies and also underscore the role of farm animals in a circular food system (Schader et al. 2015, van Zanten 2018, 2019, Sandström et al. 2022), though caution needs to be taken for economic feedback effects that might lead also to an increase of GHG emissions (Latka et al., 2022).

The interrelations between feed import dependence of the EU and food security issues in the EU and globally are manifold and hence require a food systems approach.

Interlinkages with other drivers

Competition for land and crop use as a food security driver is directly related to many of the other drivers including food prices, intensity of production, and consumer demand/dietary choices. It has also direct interlinkages with food waste, trade, energy prices, environmental pollution and degradation, and biodiversity. These relations are not easily pinned down because of feedbacks in the food system.

Even simplistic reasoning illustrates the complex interrelations. Climate change may lead to more land becoming available in northern areas in the EU, while further hampering agricultural production in southern areas. However, while Scandinavian agricultural production may benefit from this, soils that are generally poor there may constrain the actual production benefits.

Nature restoration may lead to less land directly available for productive purposes, but it could also boost yields by making ecosystem more resilient to climatic risks by lowering impacts of droughts and floods. Biodiversity loss will affect the food system in terms of, for example natural pest control, which may lead to larger land needs for the same amount of production.

8.19. Supply chain performance

General context and what is at stake?

Households' physical access to food is dependent on the supply chain's capacity to bring food to the consumers. This capacity is in turn determined by the interplay of many services, such as transport, logistics, and the availability of packaging. The costs associated with these activities also directly influence consumer food prices and economic access to food. More generally, a well-performing food supply chain requires operation of logistics and production facilities, access to inputs and markets, well-designed and responsive regulatory environment. The perishability and seasonal nature of food products makes coordination among operators and logistics essential elements of food supply chain management to ensure an efficient movement and storage of products along the supply chain up to the final consumers.

Along the supply chain, fresh produce can be damaged during storage or transport from farms to distribution centres to retailers, in particular if quantities are not supplied swiftly to the places they are demanded, resulting in food loss. As such, a well-performing efficient supply chain can contribute to-wards the reduction of food loss, which in turn affects availability and access to food.

It should be emphasized that the food supply chain is internationally highly interconnected and disruptions have increasingly been of transboundary nature. This is reinforced by the fact that the EU is an important global player on international markets. The EU is primarily vulnerable to disruptions on international markets on the input side, particularly for fertilisers, fossil energy and feed protein for which it is a net importer. But, since the EU is largely self-sufficient and even net exporter for many agri-food products, the import dependency for food is not a vulnerability for the EU food systems: disruptions in international agricultural commodity markets are not expected to significantly threaten food availability. Nonetheless, the EU is vulnerable to disruptions on international market for some food commodities with high import dependency such as coffee and cocoa, tropical fruits, or fish. As a large food producer and exporter, disruptions in the EU food supply chain (e.g. through bottle-necks in logistics) may contribute to global food security issues (Andrei et al. 2021; EUMOFA 2021; Hel-legers 2022).

An illustration of the difficulties arising from disruption in transport and logistics is the impact of the blockade of Ukraine's seaports by Russia on the trade of cereals and oilseeds. Before Russia's war against Ukraine, Ukraine exported up to 5 Mt of grain per month – 95% through the Black Sea ports. These flows were redirected towards rail, road and inland waterways, and then onwards through EU ports. Harnessing this alternative route is the objective of the actions set out in the Commission's Solidarity Lanes Communication adopted on 12 May 2022. The EU imports 52 % of its maize from Ukraine. Maize is an important ingredient in animal feed, and supply disruptions could affect in particular pig and chicken farms across Europe. The solidarity lanes have carried 17.1 million metric tons of grain and oilseeds until 10 November 2022. The reopening of the Ukrainian Black Sea ports for grain exports in July has alleviated the bottleneck problems. According to the EU reporting, as of 10 November 2022, voyages from Ukrainian ports have carried 10.2million metric tons of grains and other foodstuffs (UN 2022).

Current assessment – 2022-24

The COVID-19 crisis and ensuing recovery period were characterised by some food supply disruptions related to transport and logistics bottlenecks. A key bottleneck during the COVID-19 crisis was sea-bound transportation, mainly caused by the disruption of the shipping sector and steep increase of the cost of container and bulk transport costs. Intra-EU road and train transportation faced fewer problems, thanks to the introduction of the Commission's 'Green Lanes' initiative (Deconinck et al. 2021; Di Marcantonio et al. 2022). The situation improved along 2022 with a downward trend for transport costs due to investments in the sector and reduced demand due to lower economic growth, despite Russia's war against Ukraine and new restrictions related to COVID-19 in China delayed the return to nor-mal.

In addition to a persisting shortage of truck drivers and other labour for transport in the EU, the major remaining factor affecting the functioning of the food supply chain are disruptions caused by Russia's war against Ukraine. In Ukraine, active fighting has damaged inland transport infrastructure and sea-ports, as well as storage and processing infrastructure. While sea ports were blocked from February to July 2022, the period when Ukraine typically ships most of its maize, the development of Solidarity lanes in the EU and the UN brokered agreement on trade of food and fertilisers in the Black sea and have eased the situation (Laborde and Glauber 2022).

The functioning of the food supply chain is, however, highly dependent on transport and therefore also on fossil fuels. The surge in energy prices is likely to increase the costs of different supply chain activities and transport in particular. This can result in further upward pressure on consumer prices for food. In addition, it's been noted that the increase in insurance costs for vessels sailing into the Black Sea has exacerbated the already elevated costs of maritime transportation (FAO 2022).

Forward looking – 2030

The Commission needs to continuously monitor the potential disruptions in the EU and globally and prepare appropriate response. Future implications of the current crisis depends to what extent disruptions in logistics and access to input and trade persist. As the experience from the COVID-19 pandemic showed, food chain is quite capable to adjust itself and to withstand certain shocks implying that a part of shocks induced by Russia's war against Ukraine will be absorbed through stakeholder's changes and adaptation in production and consumption.

However, continued disruptions may bring about new or exacerbate the existing food security issues (e.g., in developing countries and in Ukraine itself). Any crises affecting food security is different and effects cannot be easily generalised based on past crises. Relevant is not to focus on the specific plan but on building a planning process so that it can serve as an efficient tool for facing different types of crises that may emerge in future (Matthews 2021).

International dimension

Developing countries that are highly dependent on imports from international markets for their main staple foods are particularly vulnerable to international supply chain disruptions. Many countries in North Africa and Western and Central Asia import the majority of their wheat from the Russian Federation and Ukraine (FAO 2022), rendering them particularly vulnerable to current supply chain disruptions.

As mentioned above, inadequate processing techniques and poor storage and care during transportation will result in food loss. This appears to be particularly important for developing countries where losses during processing and transport, especially for highly perishable foods such as fruits and vegetables, are much higher (FAO, 2017). Supply chains for non-staple foods are poorly developed in developing countries, especially when it comes to advanced transportation systems, cold storage, and relatively high-tech food processing. Improving the functioning of these supply chains would increase access to nutritious food (Pingali and Sunder 2017)

Interlinkages between drivers

The availability of workers is an important determinant of the functioning of the food supply chain. Reduced availability of workers may generate supply chain bottlenecks. As mentioned above, higher energy prices may also lead to supply chain bottlenecks through affecting operation of logistics and production facilities, access to inputs and markets.

As illustrated by the disruptions caused by Russia’s invasion of Ukraine, conflict will not only disrupt production but also transport of food as a result of damages to infrastructure and other blockades. Similarly, disruptions to trade such as the implementation of export bans may affect the operation of the food-supply chain.

A well-performing efficient supply chain can, in turn, contribute towards the reduction of food loss and to lower food prices.

8.20. Food loss and waste

General context and what is at stake?

Food loss and waste refers to the decrease in quantity or quality of food along the food supply chain. There exist different definitions of these two concepts. In EU legislation, food waste is defined as any food that is disposed of as waste along the food supply chain. FAO, however, considers only food disposed of at the retail and consumption level as food waste. In this case, any food that is disposed of along the food supply chain, excluding the retail level, and is not used for any other productive use, is defined as food loss. While food loss is generally understood to cover pre- and post-harvest loss of food on farms, there is currently no definition of food loss in EU legislation.

Causes of food loss and waste differ widely along the food value chain. Important causes of food loss and waste along the supply chain range from inadequate storage conditions, processing and packaging of food, to transport infrastructure. Food waste at the retail and consumer level in turn can be linked to excess buying, influenced by too large portioning and package sizes, confusion over labels (best before and use by), or inadequate in-home storage (FAO, 2019). Cultural models of eating and attitudes towards food waste may also drive consumers' food waste behaviour (Alonso et al., 2018).

Food loss and waste reduces productivity and can reduce food availability. In addition, it has a significant environmental impact including unnecessary greenhouse gas emissions and puts unnecessary burdens on the already limited natural resources, such as land and water use. In addition, the loss of marketable food can reduce farmers' income and increase consumers' expenses.

By increasing the efficiency of food systems and supporting consumer behavioural change to avoid unnecessary discarding of food, it would be possible to feed a greater number of people with the same food production. Reducing food loss and waste can therefore contribute to meet the expected growing demand for food whilst ensuring that our food system operates within planetary boundaries. Moreover, reducing food loss and waste could contribute to food price decreases, thereby potentially improving economic access to food. (e.g. Boysen-Urban et al., 2022). Reaching food security, however, inevitably implies certain levels of food loss and waste as a result of maintaining buffers to ensure food stability, discarding unsafe foods, and the fact that higher-quality diets tend to include more highly perishable foods.

The link between the reduction of food losses and waste and food security in Europe (and worldwide) may not always be direct. While the reduction of on-farm losses is likely to have positive impact on food security, the reduction of food waste further along the food supply chain contributes to food security when carried out according to the "food use" hierarchy, that is, prioritising high value uses in the food and feed chain. The primary focus of food waste prevention is to act at source, ensuring that the amount of food produced matches customer and consumer demand.

Current assessment – 2022-24

While according to the FAO data, Europe registers among the world's lowest rates of food loss and waste in the supply chain up to retail level (FAO, 2022), new practices and technologies can help further limiting food loss and waste.

In 2020, it is roughly estimated that around 10% of food made available to EU consumers (at retail, food services and households) was wasted. Most food waste occurs at the consumption level. EU households were estimated to have wasted 70 kg of food per inhabitant, accounting for 55% of the estimated 57 million tonnes of fresh mass wasted. Waste at restaurants and food services accounted for an additional 12 kg per inhabitant or 9 % of total food waste (Eurostat, 2022).

Forward looking – 2030

The potential of food loss and waste reduction is seen in an improved efficiency of the food system through the release of agricultural land, reduced emissions and lower market prices. (Lopez Barrera and Hertel, 2021; Cattaneo et al, 2021). On the other hand, several studies confirm that accounting for economy-wide effects in the assessment of food waste reduction result in a more nuanced picture, as the savings (economic resources) provoke so-called rebound effects including additional food demand or stimulating other economic activities with potentially non-intended consequences (Philippidis et al, 2019; Jafari et al., 2020; Cattaneo et al, 2021; Kuiper and Cui,2021; Albizzati et al., 2022; Boysen-Urban et al., 2022). Some authors also stress the importance of including adjustment costs in food waste re-duction assessments (Philippidis et al, 2019; Jafari et al., 2020; Albizzati et al., 2022; Boysen-Urban et al., 2022).

International dimension

Food loss and waste tend to be a more serious problem in lower-income countries because of poor drying, cold chains and storage handling or weak infrastructure. In addition, these are expected to further increase with climate change and in particular with increasing temperatures. The global percentage of food lost and wasted after harvesting at the farm, transport, storage, wholesale and processing levels is estimated at 13% in 2016 and 13.3% in 2020. At the regional level, sub-Saharan Africa has the highest losses at 21.4% (FAO, 2022).

It should be noted that post-harvest loss and waste assessment in the field requires significant re-sources and quantitative data are scarce in low-income countries. The EC the JRC has been involved in the development and continuous improvement of the African Postharvest Losses Information system (APHLIS) since its launch in 2009.

Achieving the SDG of halving food waste and reducing losses globally, is estimated to lead to improved production efficiency in the food chain and lead to global food price decreases, indicating a positive impact on availability and economic access to food and could thus contribute to reducing food insecurity. While there are trade-offs that require careful analysis, the overall environmental impacts have been evaluated to be positive (Boysen-Urban et al., 2022). Kuiper and Cui (2021) emphasise that next to positive environmental impacts, limiting food loss and waste would improve global food security, especially in low income regions.

In addition, in the context of developing countries with relative high on-farm food loss and a large share of the population engaged in agriculture, reducing food loss and waste would not only contribute to food availability, but also to income growth and therefore food access. Even when physical quantity of on-farm food loss are relatively low, the value and revenue loss associated with releasing harvest onto the market early in order to limit losses due to poor storage facilities may be much larger (Sheahan and Barrett, 2017).

Interlinkages with other drivers

Plant pests and diseases are a major cause of pre-harvest food losses. In addition, climate change and especially rising temperatures can increase food loss and waste in the food supply chain. In turn, food loss and waste is strongly linked (being both a cause and an effect) to economic drivers. These relationships are, however, complex. Household income, for example appears to affect households' food waste behaviour in different ways. Setti et al. (2016), for example, find that Italian consumers in high income brackets show a tendency to waste certain products such as fruits and vegetables more frequently. Yet, the opposite seems to hold for other foods. While food prices may affect decisions with regards to food waste, food loss and waste can also affect food prices. This might generate indirect effects possibly cascading to food choices. For instance, consumers, especially in high-income countries could respond to changed prices by increasing the proportion of animal and processed products in their diets. Given a potential effect on and of food prices, changes in food loss and waste can also impact farm income and trade.

8.21. Governance and legislative framework

General context and what is at stake?

With food supply at the basis of the stability of societies since ancient times, public policy always has and continues to play an important role as driver of food security. The supply chain challenges during the COVID-19 pandemic in 2020 and the food security challenges linked to the unprovoked Russian invasion of Ukraine in 2022 illustrate the need for public intervention in crisis situations. But in view of the risks inherent to farming and fishing (weather, pests and diseases, market volatility), as well as its fragmented production structures, structural policies exist in practically all nations.

Current assessment – 2022-24

The European Union has established its Common Agricultural Policy in 1962, to meet the objectives laid down in the Treaty in 1958 that have not changed since. Similarly, the Common Fisheries Policy finds its origin in the founding treaties of the Union. These policies have changed considerably, however. In response to challenges of budgetary, trade, environmental, political, etc. nature, but also to respect further additions to the founding treaties regarding the environment, consumer protection, animal welfare, etc.

The Farm to Fork legal initiatives proposed by the Commission so far present now a zero effect on food security, as they are only proposals. They are designed to improve food security over time..

It would be a mistake, however, to only consider EU policies in the context of the governance framework that affects food security. Governance affects all drivers of food security, and therefore any local, regional or national laws or institutions in relation to those drivers are important. Policies on health, taxation or education, for example, are crucial and largely regulated at national or regional level in the EU.

Similarly, it is of great importance to consider international institutions, treaties and systems of governance, as agricultural markets are global markets and as practically all nations are interdependent and import or export part of their food stuffs. Furthermore, in fisheries the state of the stock is very much dependant of the sustainability of fishing operations and governance globally. The United Nations and its different agencies (e.g. FAO, WFP, IPCC, ILO), the World Trade Organisation, and many other institutions help govern the food system at global level.

The key questions in relation to the "governance framework" as driver of food security is whether public policies and institutions are able to deliver on the different dimensions of food security (availability, access, utilisation, stability) in both the short and the long term.

Forward looking – 2030

With the Green Deal, and in particular its Farm to Fork Strategy, the European Commission identified key actions to reform its governance of the European food system, to be able to ensure food security in both the short and the long term. Many of the targets in these Green Deal strategies are set for 2030. In its Farm to For Strategy, the Commission said:

"A sustainable food system must ensure sufficient and varied supply of safe, nutritious, affordable and sustainable food to people at all times, not least in times of crisis. Events which affect the sustainability of food systems do not necessarily stem from the food supply chain itself but can be triggered by political, economic, environmental or health crises. While the current COVID-19 pandemic has no connection to food safety in the EU, such crisis can place both food security and livelihoods at risk. Climate change and biodiversity loss constitute imminent and lasting threats to food security and livelihoods. In the context of this strategy, the Commission will continue closely monitoring food security, as well as competitiveness of farmers and food operators."

The strategy also identifies the importance of short-term food supply:

"The Commission will step up its coordination of a common European response to crises affecting food systems in order to ensure food security and safety, reinforce public health and mitigate their socio-economic impact in the EU. Drawing on the lessons learned, the Commission will assess the resilience of the food system and develop a contingency plan for ensuring food supply and food security to be put in place in times of crisis. The agricultural crisis reserve will be revamped so its full potential can be used upfront in the case of crisis in agricultural markets. In addition to risk assessment and management measures to be activated during crisis, the plan will set up a food crisis response mechanism coordinated by the Commission and involving Member States. It will be comprised of various sectors (agriculture, fisheries, food safety, workforce, health and transport issues) depending on the nature of the crisis."

This contingency plan was published in November 2021, and it also created the European food security crisis preparedness and response mechanism (EFSCM), which was consulted on these drivers of food security in November 2022. Moreover, on 23 March 2022, the Commission published a Communication entitled 'safeguarding food security and reinforcing the resilience of food systems' , addressing not only the short term challenges of food security after the Russian invasion of Ukraine, but also identifying the long term objectives of resilience, in line with the Green Deal. Similarly, the 9 November Communication on fertiliser embodied both a short term and long term dimension.

The reform of the Common Agricultural Policy as well as the wider action plan of the Farm to Fork Strategy and the Biodiversity Strategy aim to improve the governance framework as a driver of food security in the EU. These Green Deal initiatives aim for increased sustainability of the food system in the long run, thus contributing to food security. In view of its horizontal nature, the forthcoming framework law for sustainable food systems may be mentioned specifically

International dimension

The policy response to the ongoing food security crisis caused by the Russian unjustified aggression to Ukraine, illustrates the importance of global public governance. To coordinate the global response to the ongoing food security, energy and finance challenges, the Global Crisis Response Group on Food, Energy and Finance was established by the UN Secretary General. In response to the food crisis, several initiatives have been launched, and among the most important ones, the Global Alliance for Food Security (G7 presidency and the World Bank), FARM (France and the Rome-based UN food agencies), the US Roadmap for Global Food Security - Call to Action as well as the Global Fertiliser Challenge.

These initiatives mainly aim to:

- Increasing humanitarian aid;

- Supporting local production;
- Investing in climate-resilient agriculture;
- Promoting open trade.

The World Food Programme (WFP)'s annual operational requirements are at an all-time high of EUR 24 billion, with confirmed contributions so far at EUR 9.47 billion. WFP aims to support a record 153 million food insecure people in 2022, a significant increase from the already record-high 128 million people reached in 2021 (WFP). The agency warns about the risk that global food and nutrition needs across the globe may soon outstrip the capacity of the WFP or any organization's ability to respond.

Interlinkages with other drivers

The governance framework is a horizontal driver and is interlinked with all other drivers of food security. It is an essential element that underpins and facilitates the functioning of food systems both directly and indirectly.

8.22. Conflict

General context and what is at stake?

Various types of conflict can affect the food security of a country and/or population, including armed conflict, intercommunal conflicts, civilian's insecurity, localized violence or political crises that tend to lead to civil unrest.

The negative effects of conflicts on food security, nutrition and agriculture are an uncontested and globally recognized phenomenon (GRFC, 2017). Organized violence and conflict remain the primary drivers of acute hunger, with key trends indicating that they both continued to increase in 2022 [FAO/WFP 2022]. In 2021, 70% of people experiencing acute hunger were living in countries affected by conflict [GNAFC], and, since 2016, conflict accounts for 72% of the increase in food insecurity [IMF-FAO 2022].

Conflicts can undermine food security through several ways, but in general lead to disruption of the food systems, food production, livelihoods and assets as well as provoke displacement, all of which can directly or indirectly affect food access, food availability, utilization and stability. In some instances, food insecurity arises as an unintended consequence of fighting. In other instances, conflict parties deliberately create or exacerbate it as part of their war-fighting strategy.

New research quantifying the relationship between conflict, climate, and food insecurity suggested that in Africa at least, the increase in food insecurity is being driven by an uptick in violent conflict. An analysis of food insecurity in sub-Saharan Africa between 2009 and 2019 found that the impacts of drought, although major, remained relatively steady over the period, whereas violent conflict had an increasingly significant impact: conflicts exacerbate and prolong the impacts of drought by displacing people, affecting local supply chains, and preventing outside aid (Anderson et al., (2021).

The Global Report on Food Security (GRFC 2017) highlighted as the primary effect of conflict the displacement of populations that are forced to flee either internally or across borders, leading to a spillover effect in other countries. Displaced persons are more vulnerable to food insecurity given the loss of livelihoods and productive assets, loss of basic living and health infrastructure (i.e. shelter, water, clinics or schools). Displacement not only puts at risk the population that is fleeing conflicts but also imperils the host communities who can see their resources under increased pressure (GRFC, 2017).

A second common negative effect of conflicts is on the primary food production sector (i.e. agriculture and livestock). In many cases, the detrimental effect of the conflict on primary production sectors slows down economic progress and affects market functioning and access (GRFC, 2017). Primary production is affected in several ways: from the actual damage to planted crops and living livestock, to loss of labor due to death, displacement, recruitment by armed groups, limited or lost access to land, damages to productive infrastructure, higher input costs and lack of economic resources to invest in the sector. Besides the interruption of primary food production, the disruption of trade internally or with other countries quickly can lead to generalized or localized market dysfunction: Low market supply, rapid food price increases, lack of basic food or non-food items and difficulties in accessing markets.

An additional consequence of conflicts is the rapid macroeconomic deterioration leading in some cases to currency depreciation, inflation and lack of employment opportunities. Many conflict-affected countries have experienced macroeconomic collapses.

In conflicts that affect a large number of people, intervention of humanitarian organizations often becomes key to reduce the severity and magnitude of food insecurity. Particular challenges arise when some parts of the population are isolated or hard to reach for humanitarian intervention, when fighting has damaged roads and other infrastructure, or when conflict parties seize or block humanitarian aid deliveries. In 2018, the UN Security Council unanimously endorsed Resolution 2417, which provides a framework to address conflict-induced hunger by allowing the Council to consider its full range of tools — including sanctions — to ensure that all parties to conflict uphold International Humanitarian Law (IHL). Violations of IHL include starving civilians as a weapon of war, unlawfully denying humanitarian access to civilian populations in need and depriving people of their means to produce food (GRFC, 2019).

Conflicts can directly and indirectly affect food security in many other ways, depending on the type of conflict and its duration. It is important to also note that there can be spillover effects of conflict-related food insecurity to other countries not involved in the conflict of origin. This not only comes from the influx of displaced population as is commonly seen but also by disruption of trade with other countries particularly when a surplus producer or exporter country stops or limits its exports due to trade disruption, lack of production or sanctions. A recent example is the war that evolved in Ukraine which effected the food security of many developing countries that are import dependent from Ukraine or Russia for certain cereals and fertiliser inputs.

Current assessment – 2022-24

The estimates highlighted below refer mainly to acute food insecurity where humanitarian aid is required, namely phases 3 to 5 in the Integrated Food Security Phase Classification scale (IPC): Crisis levels (Phase 3), Emergency levels (Phase 4) and Famines/Catastrophes (Phase 5). More complete data is available for 2021 and partial data for 2022, but the situation is largely similar in terms of affected countries.

For the year 2021, GRFC finds that 193 million people in 53 countries are affected by acute food insecurity. Out of the 53 countries, 24 countries/territories covered in the GRFC faced conflict accounting for 72% of the afflicted population by food insecurity.

Between 2018 and 2021, the number of people facing severe food insecurity in countries/territories where conflict/insecurity was the principal driver increased by a staggering 88 percent – going from around 74 million to 139 million (GRFC 2022).

Conflict was the key driver in three of the four countries with populations in Famine/Catastrophe (IPC Phase 5) – Ethiopia, South Sudan and Yemen – and in seven out of the ten largest food crises.

The GRFC 2022 mid-year update, indicates the number of people in Crisis or worse (IPC Phase 3 or above) requiring urgent humanitarian assistance is forecasted to reach up to 205.1 million in 45 of the 53 countries/territories in the GRFC 2022, which represents an increase of up to 29.5 million people between 2021 and 2022 despite many populations in food crisis receiving humanitarian and development assistance, suggesting that needs continue to surpass current support and capacities.

Forward looking – 2030

The GRFC report does not have a long-term focus and its looks at the current year projections. It has assessed the situation globally with the most reliable data from 2015-2022. This gives a good period to understand the global trends for the upcoming 5 to 10 years which indicate a constant increase in food insecurity and continued increasing negative influence of conflicts on food crises. Besides IPC Phase 3 to 5, the report has also monitored IPC Phase 2 (Stress), which are the population under such stress in terms of food security that without improving conditions, could easily slide into higher severity and require humanitarian assistance. The population in this phase has come from 87.4 million in 27 countries during 2016 to 236.2 million in 41 countries during 2021, due to both an increased coverage of analysis but also due to an actual increase in food insecurity and showing a 10% increase from 2020 to 2021, with a clear deterioration in some countries such as the Democratic Republic of the Congo, where nearly 48 million people were classified in IPC Phase 2 (Stress) in 2021. Populations in this category require action from the development sector for disaster risk reduction and livelihood protection.

Interlinkages with other drivers

The GRFC highlights that all countries/territories with major food crises - mainly driven by conflict - were also affected by either weather extremes, economic shocks or both. These two drivers often fuel tensions and conflicts by increasing competition around limited natural resources and income opportunities (GRFC, 2022). Pollution and environmental degradation in general can increase the risk of conflict, while conflicts, especially if protracted, increase environmental degradation (e.g. deforestation for wood charcoal production).

Conflicts can have disruptive effects on supply chains and have negative effects on all aspects of production, planted areas, access to fields, transport, etc.. and all these factors together tend to increase food crises. Food inflation is one of several economic shocks that can cause of further fuel conflict.

Finally, food insecurity is not just an outcome of conflict but also a potential driver. The causal effects of food insecurity on conflict remain poorly understood and research remains ongoing. Still, there is robust evidence that food price shocks can trigger mass protests and unrest that can escalate into violence [Martin-Shields and Stojetz, 2019]. This is also illustrated by prominent cases such as Venezuela, Iraq, Lebanon and to some extent the Arab Spring, where food price spikes have triggered mass protests and violence. The food price crisis of the late 2000s, when cereal prices spiked due to weather shocks and trade restrictions, leading to export bans triggering riots in Haiti, Bangladesh, Egypt and Mozambique are a prominent example of this with worrying parallels with the current situation. More recently, Iraq has experienced protests as food prices spiralled upwards, with flour rising by nearly a third in price. Recent protests in Sri Lanka have been fuelled by the price hikes (food inflation exceeded 85 % in October) and shortages of fuel, key commodities and fertilisers, partly caused by the Government's earlier economic policies and impact of the pandemic, partly by the rise in crude oil and fertilisers prices because of the war in Ukraine. There are also accounts of thousands taking the streets in Sudan, to protest the coup and deteriorating economic conditions (inflation rate reached 260% in February). There are concerns about social stability in highly exposed Egypt, if price volatility persists. Similarly, in Tunisia, higher cereal prices are highly likely to increase the already high potential for protest and social unrest.

8.23. Generational renewal

General context and what is at stake?

The latest Eurostat census on EU agriculture (2020) shows that the number of farms in the EU declined by 25% the last 10 years and that the increase in the average size of the remaining farms continues.

In that process of structural change, the food sector appears to be less likely to attract young people than other sectors and the population engaged in farming and fishing in the EU is ageing: Today in the EU, only about one in five EU farm managers are under the age of 45 and the proportion of young farmers in the overall farming population is declining . Only 1% of EU farm managers are below 25 years old ([79]). Similarly, about 30% of workers in the EU fishing fleet were below 40 (STECF 2022a) and 43% of the EU aquaculture sector (STECF 2022b).

Attracting young and well-trained people is crucial for the sustainability of food production and there-fore food availability. Supporting the next generation of European farmers and fishers not only en-hances the future competitiveness of EU agriculture and fisheries, but it also helps guarantee Europe's food supplies for the years to come.

Access to land and access to credit are identified as key barriers to enter the sector (European Com-mission, 2021). The lack of attractiveness of agriculture also relates to lifestyle-oriented reasons and income differential with other professions (Coopmans et al. 2021). The deployment of farm-support services (e.g. possibility to go on vacations) and supports to on-farm diversification are among the options to address those issues.

Current assessment – 2022-24

According to the last Integrated Farm Statistics (IFS) census conducted in 2020, 20% of the European farmers are below 45 years old and around 30% are close to retirement. The share of young farmers is declining in the EU: in 2010, 24 % of farm managers in the EU were young (defined here as under the age of 45 years) but this share had fallen to 20 % in 2020 (Eurostat 2020).

For what regards fisheries the 2022 Annual Economic report shows that the age class '40-64' represents 59% of the workers in the EU fishing fleet, the employees above 65 years represent

([79]) Eurostat.

6%, while the youngest age categories ’15-24’ represent 4% and the category '25-39' represent 25%, it was un-known for 6%.

The “generational renewal challenge” is particularly acute in those Member States that combine a lower than average share of young farmers with a higher than average share of farmers above retirement age (i.e. in many countries in Southern Europe, some in Eastern Europe, and also in Ireland, Sweden and the UK) (Coopmans et al. 2020). In contrast, the situation seems more favourable in the six Member States that combine a higher than average share of young farmers and a lower than aver-age share of farmers over 64: Germany, Luxembourg, France, Slovakia, Poland and Austria (Coopmans et al. 2020). Note that since 2016 the demographics have developed heterogeneously across Member States and that the generational renewal challenge is greatly country specific.

Up-skilling, re-skilling, improving the education of farmers and fishers, and providing access to good quality and a harmonised professional training remains fundamental to ensure a viable food production. Particular attention should be paid to attracting a skilled workforce including, for example, fishers, agronomists, veterinarians, machinery, contact material specialists, sustainability experts, circular and biotech experts, food scientists, and food technologists.

Under the CAP post-2022, attracting young farmers and facilitating business development in rural are-as is one of the nine Specific Objectives. In their national CAP Strategic Plans, the Member States should develop strategies to benefit young farmers, which generally include a combination of several interventions, such as setting up income support, investments at higher rate, and cooperation. Sup-porting the next generation of European farmers not only enhances the future competitiveness of EU agriculture, it also helps guarantee Europe’s food supplies.

Forward looking – 2030

The long-term resilience and sustainability of food systems require the boosting of research and innovation and putting enabling instruments, such as training, education and information, in the hands of young farmers who can contribute the most to fostering innovation and resource efficiency.

International dimension

Farmers ageing is not solely a European problem. While the average age of farmers in the EU-28 is 51.4, it reached 58.3 in the USA, 65 in South Korea, and even 67 in Japan (CCRI et al. 2019). Moreover, while the majority of youth in low-income countries continue to work in agriculture, farming’s share of youth employment is declining (World Bank and IFAD, 2017). A general trend is that the ageing problem especially affects to small-scale farms, which are less likely to engage young people, due to problems such as land access, financing, assistant and low profitability (Żmija et al. 2020).

Given the rapid pace of urbanization in many lower-income countries, there are rising concerns about the impact of rural-urban migration among youth on the availability of workers and agricultural production. The importance and effects of these migration movements are, however, often overstated and are in reality diverse and context-specific. Using data on 31 low- and middle income counties, Cattaneo and Robinson (2018), for example, estimate a relatively modest net rural-to-urban migration flow of around 10 percent of the population. More generally, the fear of a mass exodus of youth out of agri-culture in low-income countries does not appear to be supported by the evidence (Mueller 2021; Christiaensen et al. 2020).

Generational sustainability is cornerstone in the FAO's and IFAD's global action plan for family farming (FAO and IFAD 2019). Four areas of actions are identified to support young family farmers in the coming decade with access to land, finance, knowledge and training being common with the targeted actions undertaken by the European Network for rural Development (ENRD) to strengthen generational renewal in the EU (ENRD 2020).

Interlinkages with other drivers

Demographic trends including population growth, rural-urban migration, and the changing age structure of the population affect generational renewal. In addition, generational renewal is linked to farm income (as well as and the income differential between agriculture and fisheries and other sectors), as the latter determines the attractiveness of working in agriculture. For example, succession has been found to be more likely on farms that are more profitable (Cavicchioli et al., 2018). The lack of generational renewal of farmers and fishers puts pressure on the availability of workers which can negatively affect the overall supply chain efficiency. As ageing farmers tend to be less likely to adopt new technologies, the lack of generational renewal could also affect investments in R&D.

8.24. Food choices

General context and what is at stake?

Worldwide, diets and eating patterns are increasingly transitioning towards diets high in animal and processed food products with environmental, economic and social/health consequences.

Albeit differences between countries and regions and a slight decreasing trend in the EU where meat per capita consumption is expected to drop from 69.8kg in 2018 to 67kg by 2031) (EC, 2021), such values are nonetheless 2 to 4 times higher than the recommended intake of meat (for those EU countries that have quantitative recommendations (EC, 2019). Food contributes to around 45% of the environmental impacts of EU consumers; for example, the food system contributes to around one third of the greenhouse gas (GHG) emissions ([80]). As far as primary production is concerned, in 2017, the EU-28 agricultural sector produced 10% of the EU total GHG emissions. Adding the emissions related to the production, transport and processing of feed, the livestock sector is responsible for 81-86% of total agricultural GHG emissions. (EC, 2020a). Food choices and dietary patterns can influence the efficiency of energy and resources use in our current food system. In an overstrained world, including the EU, switching to more plant-based diets would contribute to food security as a considerable proportion of agricultural land is used to produce feed rather than food for direct human consumption. Moreover, livestock production is more than six times less efficient than crop production in terms of protein output (Nijdam, Rood, and Westhoek 2012), although it should also be considered that 86% of proteins used by livestock are not edible as human food ([81]).

In addition, our current eating patterns are fueling the rising burdens of several non-communicable diseases like cardiovascular disease, obesity, diabetes and cancer. In the EU, with a few exceptions, the consumption of fruit, vegetables, legumes, nuts, whole grain and dietary fibre as well as potassium is lower than the recommended intake levels while total intake of energy, red (including all processed) meat, as well as saturated fats , total and free sugars

([80]) EDGAR - The Emissions Database for Global Atmospheric Research (europa.eu)

([81]) de Vries M., de Boer I.J.M. 2010. Comparing environmental impacts for livestock products: A review of life cycle assessments. Livestock Sci. 128, 1–11.

and sodium are higher (European Commission, 2020b, 2022a; EFSA 2021, EFSA 2022, Rippin et al., 2017, 2019, Willet et al., 2019). Cardiovascular diseases (CVDs) are one of the most prevalent diseases in the EU with estimates pointing to almost 63 million people affected by the condition and almost 2 million deaths per year (European Commission, 2019b) (European Commission, 2018a). It is estimated that in the EU region, 59% of adults and about one third of children aged 5-9 years have excess weight or obesity, and 23% obesity (OECD, 2019) and perhaps counterintuitively, these co-exist with micronutrient deficiencies as well. The burden of micronutrient deficiencies is heaviest in Sub-Saharan Africa and South Asia (Global Nutrition report, 2021) but micronutrient deficiencies are prevalent globally, including in EU Member States y, with some evidence of recent increases (Han et al. 2022). Low consumption of micronutrient-rich foods such as fruits, vegetables, pulses may be underlying these. Only 12% of the EU population consumes the daily recommended five portions or more of fruits and vegetables (2019 data, Eurostat, 2022).

Sustainable (including healthy) food choices are intricately dependent on the food environment where they are made and how easy the access to adequate, sufficient and nutritious food is. Socio-economic groups that struggle with lower incomes or long working hours are often limited to making unhealthier nutrition choices (OECD, 2022). In addition, disruptions in the food supply chain expose more households to situations of vulnerability to food insecurity exacerbating health inequalities (OECD, 2022). For example, access to sustainable food choices is difficult for low-income households (Penne and Goedemé 2021; Brannen and O'Connell 2022).

Food poverty and food insecurity (moderate and severe) exist in many EU countries. In 2020, an estimated 3.1 billion people could not afford a healthy diet globally and this number is expected to continue rising (FAO, 2022). In Europe, it is estimated that 58 million people (7.8%) are affected by moderate or severe food insecurity (FAO, 2022). The highest prevalence of severe food insecurity, often associated with prevalence of undernourishment, is observed in Southern Europe with 2.8%. As regards food poverty in the EU, the percentage of the population that cannot afford a healthy diet (in accordance with national guidelines) across EU countries ranges from 2.5% in Finland to more than 40% in Croatia, Greece, Bulgaria and Romania (Penne & Goedemé, 2021). About 1 in every 15 people (6.8 %) within the EU in 2019 were unable to afford a meal with meat, chicken, fish, or a vegetarian equivalent every second day. This value is higher for females and for older adults and can reach values as high as 27.6% in Bulgaria for example (EC - Eurostat, 2021).

Current assessment – 2022-24

Initiatives such as food reformulation, public procurement, school meals, advertising, have the potential to facilitate healthier food choices and the transition towards more sustainable diets, with favourable consequences for the society, public health, the environment and food security. Nevertheless, the food system is currently still exposed to shocks; food inflation and higher energy prices caused by the war against Ukraine coupled with stagnating wages can reduce the affordability of sufficient, safe, nutritious food for many households in the EU (EIB, 2022). Further, food inflation is expected to affect consumers' choices by shifting consumption from more to less expensive food and potentially of lower nutrition quality and sustainability. Again, low-income households and vulnerable groups will be affected disproportionally but to a different extent across EU MS (Regmi and Meade 2013, EIB 2022). Indeed, the EIB estimates that the increase in food and energy prices increased the share of people at risk of poverty across MS between 0.1% and 4.3% (EIB 2022).

Overall, the Russia's war against Ukraine may jeopardize the accomplishment of the Sustainable Development Goals (SDGs) for the end of poverty (SDG 1), zero hunger (SDG 2), good health and well-being (SDG3) and responsible consumption and production (SDG 12).

Forward looking – 2030

The 2022 Strategic Foresight Report has highlighted the need for an accelerated transition towards sustainability to increase resilience in the context of food system shocks that threat food security in the EU region (EC, 2022c) and the EU Farm to Fork strategy as well as Europe's Beating Cancer Plan underline that a transition towards more plant-based diets is essential to promote health and achieve sustainable food systems (EC, 2020).

A shift to a plant-based diet has the potential to reduce the land use for agriculture by up to 75%, and thus contribute to global food security (Ritchie H, 2021). Transitioning towards more plant-based diets in line with dietary guidelines has also been linked to better health and environmental outcomes compared to actions focused in food security concerns only (Springmann et al, 2018)). Increased uptake of plant-based diets has been associated with better health, better air quality, reductions in premature mortality as well as substantial reductions in greenhouse gas emissions and ammonia emissions (Himics et al, 2022)

EU citizens consume, on average, 58% of animal-based proteins and 42% of plant-based proteins, this ratio being constant over the last decade. Dairy represents 40% of animal-based proteins intake, pigmeat, 21%, poultry meat, 16%, bovine meat, 10% and eggs, 7%. Reversing the rise in overweight and obesity rates across the EU is critical, including moving to a more plant-based diet.

In 2017, livestock represented 40% of the total agriculture added value and European industries linked to animal production (milk and meat processing, feed for livestock) have an annual turnover of approximately EUR 400 billion. Livestock farms employ around 4 million people in EU and livestock contributes to shape the EU farming system based on family farms: 58% of European farms hold animals and the average livestock farm typically has 1 to 2 workers plus the family owner (EC 2018b, Peyraud and MacLeod 2020). The strong dependency on imported soya and maize for feed makes EU livestock farmers vulnerable to external conditions. Self-sufficiency can be a problem and a dietary shift can contribute to reduce this dependency. As well, the source countries for these imports could eventually, at least partially, use their agricultural production area to produce food for other world regions (inc. the EU). The interrelations between feed import dependence of the EU and food security issues in the EU and globally are manifold and hence require a closer assessment within a food systems approach.

International dimension

Globally, economic development has been driving dietary changes and rising incomes and urbanization have led to the current dietary patters. Many low and middle-income countries are still experiencing this "nutrition transition" and the coexistence of under and overnutrition as discussed above. The distortion of these trends that can be anticipated from the war against Ukraine with consequences for global food demand. Higher food and energy prices negatively impact food consumption of populations with lower incomes particularly in developing countries, as these groups spend a larger share of their incomes on food. In addition to the 720 to 811 million people that already faced hunger in 2020, the war in Ukraine risks raising the number of undernourished people by 7.6 to 13.1 million people in 2022 and 2023 (FAO report). The highest increase in the number of people undernourished would take place in the Asia-

Pacific region (up 4.2 to 6.4 million), followed by Sub-Saharan Africa (up 2.6 to 5.1 million) and the Near East and North Africa (up 0.4 to 0.96 million) (FAO 2022).

On the transition to a higher intake of plant-based foods, it is important to note that food and feed markets are well integrated internationally. Decreasing EU feed imports would, therefore, lead to decreased cropland demand in the exporting countries and allow these countries to dedicate more of its area to food crop production, which entails potential benefits for global food security. However, if an EU feed import decrease implies increased EU production of feed crops, this would also lead to less EU production and exports of food crops (Henseler et al. 2013, Karlsson et al. 2021), with potentially adverse impacts on global food security. Thus, reducing EU feed imports for livestock in a sustainable way would ultimately require both decreased consumption of livestock-based food (to support the nutritional requirements of EU diets) as well as optimising livestock production (Karlsson et al. 2021).

Interlinkages with other drivers

Food choices have a major impact on climate change, biodiversity, environmental pollution and degradation, and soil health. Furthermore, they can affect farm income and food prices, competing land uses and, in general, trade dynamics. They are also strongly linked to food loss and waste, meaning that they can both increase food loss, and be influenced by it. Consumption patterns and shifts in consumer preferenceswill also affect trade, use of land, land management and energy prices.

The interlinkage with governance and policy making is crucial here too. The onus of healthier and more sustainable food choices is not on the individuals making them. Food choices are determined by the food environments where individuals make them, and these environments are shaped by all actors, most importantly by policy makers and food business operators.

8.25. Demographic trends

General context and what is at stake?

The question of population growth has long been connected with the topic of food security. While the global population growth rate is declining, the world’s population is projected to grow to around 8.5 billion in 2030 and reach a peak of around 10.4 billion people during the 2100 ([82]). In the context of a grow-ing population with growing food demand, global food production will have to continue to increase, though by how much will depend on consumer food choices and the ability to reduce food losses and waste. While the most often cited required rate of increase of food production is 60% (Alexandratos and Bruinsma 2012), other studies point estimates between 35% and 56% (Van Dijk et al. 2021).

The spatial distribution of the population within countries is expected to change as well. While an estimated 57% of the global population is living in urban areas today, this is expected to rise to 68% in 2050 (UN DESA 2019). Urbanization is often expected to put additional stress on food systems through changing food demand. Comparisons of diets in rural and urban settings reveal significant differences. Often-cited changes include decreased consumption of staple foods and greater consumption of pro-cessed and animal-source foods. Yet, the understanding of urbanization as a driver of changes in food consumption remains limited (Cockx et al. 2018).

([82]) UNDESA’s World Population Prospects 2022 (https://www.un.org/development/desa/pd/sites/www.un.org.development.desa.pd/files/wpp2022_summary_of_results.pdf).

In part because of its potential effects on food demand, urbanization is also believed to be an important driver of change in the production, trade, and processing of food (De Bruin and Dengerink 2020).

Current assessment – 2022-24

The growth rate of the EU population was near 0% in 2020 and 2021. With some positive but very limited growth expected for the next years. With 79 per cent of the population residing in urban or inter-mediate regions, the EU is among the most highly urbanized regions in the world. The shift of the population towards urban areas continues albeit at a relatively slow and uneven pace (Eurostat 2021). The population in urban regions grew by 3.8 million between 2014 and 2019, the rural population dropped by 0.8 million over the same period. The overall growth rate of the proportion of the EU population living in urban areas is, however, close to 0 % (UN DESA 2022).

Forward looking – 2030

While the global population is projected to continue growing until the 2080s, the EU-27's population is projected to peak to 449.3 million in 2026 and then gradually decrease. Some countries are still projected to grow, with net migration being the main contributor to population growth (Eurostat, 2020). In addition, the EU population structure is shifting towards older ages. While there were almost three persons of working-age for every elderly person in 2019, by 2100 this ratio is projected to be less than 2:1. Ageing has been associated with changes in eating behaviour (e.g. Drenowski and Shultz 2001).

The proportion of the EU population residing in urban areas in expected to increase further. Between 2019 and 2050, the overall urban population is projected to increase in 15 EU Member States, ranging from +2.3% in Croatia to +35.4% in Malta. At the same time the urban population is projected to de-crease in nine EU Member States. 20 Member States are projected to record declines in their overall rural populations. The population residing in rural areas is expected to grow in just 4 Member States.

International dimension

More than half of the population increase projected through 2050 will derive from Sub-Saharan African countries. The population in many countries in sub-Saharan Africa is projected to double between 2022 and 2050, putting additional pressure on already strained resources and challenging policies aimed to reduce poverty and food insecurity (UN DESA 2022).

The rural population of the world has grown slowly since 1950 and is expected to reach its peak in a few years. Urbanization has been faster in some less developed regions compared to historical trends in the more developed regions. The rate of urbanization is the highest in Asia and Africa. These two regions are urbanizing faster with the proportion urban increasing by 1.3 and 1.1 per cent annually be-tween 2015 and 2020 (UN DESA 2019).

Continuing urban sprawl is changing land use patterns rapidly in many less developed countries. In addition, rapid urbanization and rural-urban migration flows have given rise to concerns about the availability of (young) workers for farming. The importance and effects of these migration movements are, however, diverse and context specific (Cattaneo and Robinson 2018). More generally, the fear of a mass exodus of youth out of agriculture in low-income countries does not appear to be supported by the evidence (Mueller 2021, Christiaensen et al. 2020).

Interlinkages with other drivers

The ageing and declining population of the EU poses challenges in terms of generational renewal and the availability of workers for the food value chain.

These demographic trends also affect land use. The migration of the EU population to cities is believed to be one of the factors driving agricultural land abandonment. In addition, urban population growth is likely to contribute to the expansion of built-up areas (Foresight 2022).

Annex I: Synopsis report - Stakeholder consultations

In order to ensure the involvement of stakeholders in this analysis, two oral consultations have been organised on 19 October and 14 November 2022 to collect their views and opinions regarding food security drivers. The events have seen the overall participation of approximately 217 stakeholders and institutions' representatives, among which trade associations, non-governmental organisations, Member States authorities and Members of the European Parliament. The interventions provided valuable insights that fed into the analysis of food security drivers in the non-paper. This synopsis report aims at gathering and summarising such inputs, organising them in accordance to the conceptual framework set out in the analysis.

Feedback overview

The feedback received shows general acknowledgment of the wide array of drivers of food insecurity and of the interlinkages among them. Stakeholders have mentioned several environmental, economic and socio-cultural factors impacting the availability and safety of food, as well as suggested approaches and solutions to turn them into enablers of more resilient and sustainable food systems.

Biophysical and environmental drivers

There was widespread agreement among stakeholders that on the main threats to food security is **climate change**. As a result of global warming, extreme weather events such as droughts, floods and fires are becoming increasingly frequent. Such events coupled with weather unpredictability are already negatively impacting agricultural yields and undermining the economic sustainability of farming businesses. Moreover, it has been argued that the natural resources sustaining food production, namely soil and biodiversity, are degrading and declining at an alarming pace due to the use of **agro-chemicals** in conventional production practices. On this note, stakeholders have called for the application of alternative and less environmentally degrading farming techniques, such as cellular agriculture, vertical farming, organic agriculture and agroforestry.

Among the biophysical drivers, contributors have also pointed out at **animal welfare** as an important factor impacting the safety and quality of meat products, and called particular attention on the role of animal nutrition and management of animal diseases in this context. Similarly, contributors have shed attention on the importance of plant health protection and seed treatment against pests and pathogens for growing healthy and high-yielding crops.

Technology and innovation drivers

Throughout the consultations with stakeholders, an aspect that has frequently emerged is the potential of innovation and technology to contribute to food security. On the one hand, stakeholders have highlighted the importance of **research and development** in plant and seed breeding, livestock medicine, alternative proteins, such as insect farming, and agricultural techniques, including agro-ecological practices, to diversify and optimise production. On the other hand, it has also been pointed out that that the **application of technology** for land management purposes, such as satellite imagery and field sensors, could contribute to enhance productivity and thus food availability.

Economic and market drivers

Economic drivers of food security have been widely mentioned by stakeholders during the consultations. **Food affordability** has been noted by the large majority of stakeholders as one of the main factors impacting food security, as this underpins the capability of consumers to purchase and consume quality and healthy food. In particular, the **availability and the costs of agricultural inputs** are key variables driving food prices. Another factor negatively impacting the cost of food that was mentioned by stakeholders is **speculation in the international commodity market by financial actors,** which dictate food companies' strategy based on a short-term perspective geared toward maximizing the cash flow for their shareholders. Contributors also highlighted the excessive corporate concentration throughout the industrial food chain, which can undermine competition and create distortions in the market prices of food products. In line with this, a correctly functioning **European single market and fair competition** have been acknowledged by stakeholders as important drivers of food security.

Several contributions have focused on supply chain considerations. Given the tight interdependence between countries for food and input exchange, **trends in global trade** have been indicated by stakeholders as an important variable impacting food security. On this note, it has been highlighted that the **diversification of origins** can ensure the continued supply of inputs and foods and better resilience in the case of shortages and crises. On a similar note, it has been pointed out that the involvement of a diversity of players in the food supply chain, including small and medium size enterprises, can better ensure food security, as it allows to cover the whole territory and the full range of products. Stakeholders have also noted the importance of **traceability and safety** of products imported from outside EU borders to achieve food security.

On a more critical note, some stakeholders have underlined that the **reliance of agriculture upon imports** of agrochemicals, fossil fuels, feeds and veterinary medicines makes Europe vulnerable to market shocks and prone to experience food price inflation. In order to tackle this vulnerability, shorter, more localised supply chains have been pointed out as a potential solution to enhance resilience. This also aligns with contributions advocating for the achievement of food sovereignty versus dependence on external outlets for basic food needs.

Food value chain drivers

Several aspects impacting food security throughout the food value chain have been mentioned by stakeholders. At farm level, it has been highlighted that the **use of land** for the cultivation of animal feeds and biofuels takes valuable resources away from food production for human consumption. At processing and distribution levels, **logistics** has also been identified as key contributor to food security, and more specifically the effectiveness and coordination of rail and other river transport systems across Europe and the efficiency of food storage systems. At retail and consumption level, stakeholders also mentioned the importance of **packaging** for mitigating food waste and preserving the hygiene of food stuffs.

Political and institutional drivers

The inputs from stakeholders also featured considerations over the political and institutional factors impacting food security. On the one hand, it has been mentioned that **national and supra national agricultural policies and subsidies to farmers** play a key role in enabling the primary sector to maintain productivity while transitioning towards more sustainable agricultural practices. On a more global perspective, stakeholders pointed out the importance of **international cooperation** to ensure resilience of international commodity chains and thus food security. In this sense, there was widespread agreement among stakeholders that the current **geopolitical instability** caused by the Russian invasion of Ukraine is posing immediate and tangible threat to food security, as it is impairing the transportation and distribution of inputs upon which many countries depend outside Ukrainian borders.

Socio-cultural drivers

It has been pointed out by stakeholders that socio-cultural aspects such as **dietary choices and their changes** exert an influence on food security. This has been raised in particular by organisations supporting alternative protein products, which if widely consumed would enable a shift from land and resource intensive meat based diets to more sustainable choices. With regards to food utilization, stakeholders have underlined that **food waste** negatively impacts food security as it leads to the loss of precious resources. The role of **food donation** by charities has been pointed out as another important driver of food security, as such practice cushions crisis-induced supply chain disruptions and market failures.
With regards to the food labour market, stakeholders have mentioned that the **inadequate working conditions and low wages of farm workers** can drive manpower away from this sector and thus pose threat to food security. Similarly, it has been highlighted that the rising production costs and difficulties in accessing credit can discourage youngsters to start an agricultural business, leading to a decreasing **generational turnover** within the primary sector.

Demographic drivers

Stakeholders have highlighted that the **growing trends of global population** can exert pressure on food production systems, thus impacting overall food security.

Other considerations

During the consultations, stakeholders have raised issues of horizontal and cross-cutting nature which affect more or less directly the availability and safety of food. It has been noted that **farming and fishing are largely dependent upon other sectors**, such as information technology and transport, and thus blockages or dysfunctionalities in the latter would negatively affect food chains.

Regarding food safety, it has been noted that the risk of **nuclear incidents** could threaten food security by polluting primary resources sustaining food production.

On the food consumption side, stakeholders have underlined that, along with **food products labelling, marketing campaigns** play a key role in influencing consumers' decisions, and thus indirectly affect land use choices.

Lastly, the importance of **free movement of workers**, both within the EU and from outside the EU, has been highlighted as key for food security, as it ensures the availability of seasonal workers within the primary sector during harvest seasons.

Short term versus long-term drivers of food security: results of live poll

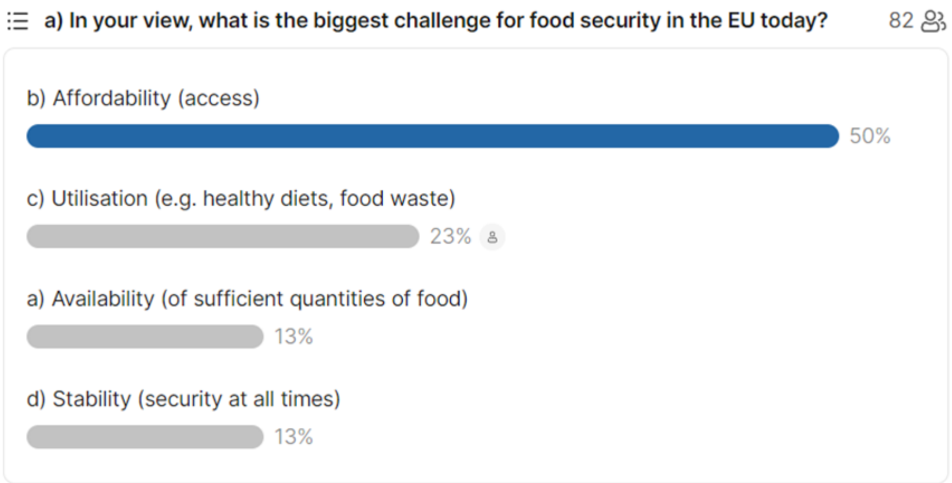
To start the debate on the drivers of food security during the second oral consultation, participants were asked to choose which out of four dimensions of food security (as established by the FAO) they considered the biggest challenge in the EU today. The results of this poll using the App Slido, were as follows:

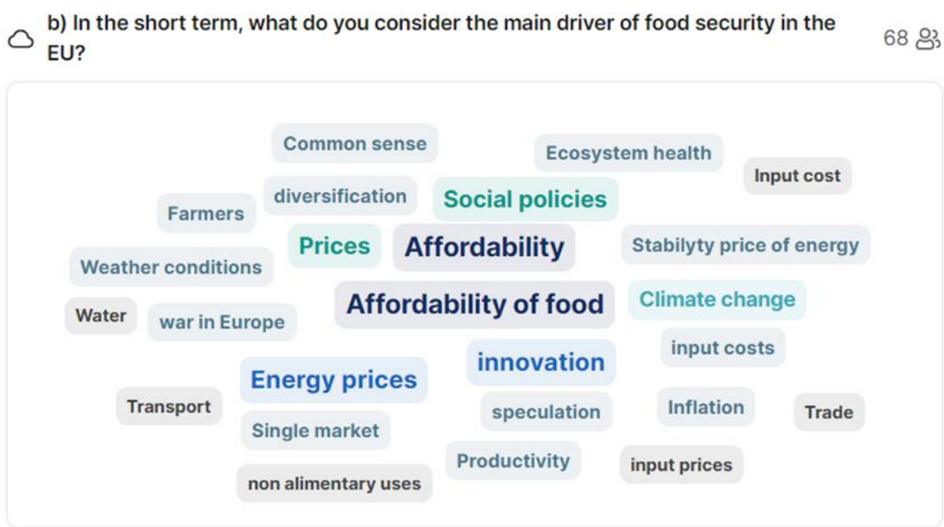
The majority of participants (82) considered affordability as the major challenge for food security in EU27. After a first round of discussion, a new round of polls (with two questions) took place.

The two polls aimed to identify among participants the key drivers of food security, according to their impacts (either short or long term). Participants were asked to identify in two different questions, which specific driver they considered most important for the EU in the short run, as well as in the long run. The results of these questions were presented as ‘word clouds’ using the App Slido.

According to the participants’ input, the main short term drivers of food security in the EU are affordability, energy prices, innovation, social policies and climate change.

The word cloud shows that participants considered climate change and climate mitigation as key driver, with innovation, and diets in second place. The diverse results also highlighted generational renewal, EU policy, diversification and sustainability as important long term drivers of food security in the EU.






c) In the long term, what do you consider the main driver of food security in the EU?
speculation
sustainality of diets
soil degradation
Generational renewal
Policy
Single Market
Sustainable Farming
EU policy
Innovation
soil health
Trade
new generations
climate change
Climate mitigation
Pests
Productivity
Workforce
Diversification
Diets
Sustainability
Agroforestry
Smart technologies
More plant-based diets.
climate conditions
Human capital
Hide results
Show Q&A

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