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Climate change adaptation in the agriculture sector in Europe

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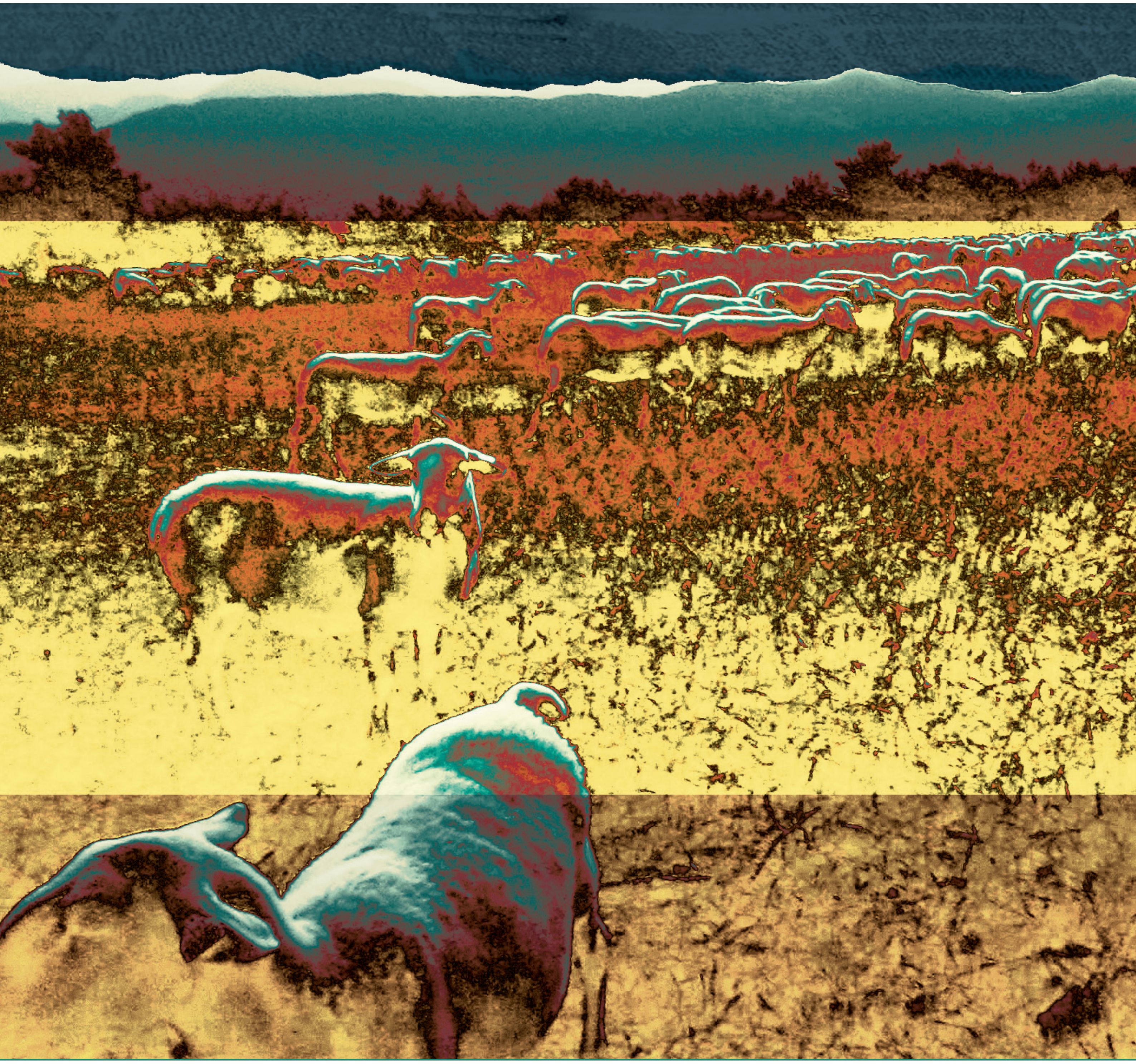

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Executive summary

Key messages

- Climate change has an impact on European agriculture in a number of ways. Climate change has already negatively affected the agriculture sector in Europe, and this will continue in the future. Future climate change might also have some positive effects on the sector due to longer growing seasons and more suitable crop conditions. However, the number of climate extreme events negatively affecting agriculture in Europe is projected to increase.
- A cascade of impacts from climate change outside Europe may affect the price, quantity and quality of products, and consequently trade patterns, which in turn may affect agricultural income in Europe. Although fodder and food security in the EU will probably not be an issue, the increase in food demand could exert pressure on food prices in the coming decades.
- The EU strategy on adaptation to climate change and the common agricultural policy have enabled adaptation actions in the agriculture sector. The new proposed common agricultural policy for 2021-2027 has adaptation as a clear objective, which could lead to EU Member States having to increase their financing of adaptation measures in the sector.
- The EU Member States have defined the agriculture sector as a priority in their national adaptation strategies or national adaptation plans. Measures at national or regional levels include awareness raising, practical measures to decrease the impacts and risks of extreme weather events, or risk-sharing strategies, and developing and implementing infrastructure for irrigation and flood protection.
- There are opportunities for implementing a wide variety of existing measures at farm level that aim to improve the management of soils and water, which can provide benefits for adaptation, mitigation, the environment and the economy. However, adaptation at the farm level, in many cases, does not take place because of a lack of, among other things, resources for investment, policy initiatives to adapt, institutional capacity and access to adaptation knowledge.

Scope and introduction

Climate change affects agriculture in a number of ways. Changes in temperature and precipitation as well as weather and climate extremes are already influencing crop yields and livestock productivity in Europe. Weather and climate conditions also affect the availability of water needed for irrigation, livestock watering practices, processing of agricultural products, and transport and storage conditions. Climate change is projected to reduce crop productivity in parts of southern Europe and to improve the conditions for growing crops in northern Europe. Although northern regions may experience longer growing seasons and more suitable crop conditions in future, the number of extreme events negatively affecting agriculture in Europe is projected to increase.

A cascade of impacts from climate change on agro-ecosystems and crop production, with effects on price, quantity and quality of products, and consequently trade patterns, may in future affect the agricultural income in Europe. In the future, the economic value of European farmland may significantly change due to a combination of these cascading impacts. The magnitude of these impacts depends also on the emission and socio-economic scenarios applied. Agriculture intensification could take place in northern and western Europe, while in southern Europe and especially the Mediterranean a reduction in the relative profitability of agriculture could result in land extensification and abandonment. The overall impacts of climate change on European agriculture could produce a significant loss for the sector: up to 16 % loss in EU agriculture income by 2050, with large regional variations. The sector will need to further adapt to these changes to secure sustainable agricultural production. Farm-level adaptation can reduce losses caused by extreme events, but knowledge of all the impacts of climate change on agriculture is still limited, especially when impacts are multiplied or combined with other social-economic consequences of climate change.

The agriculture sector can also significantly contribute to reducing greenhouse gas (GHG) emissions, and therefore future actions should focus on those that have multiple benefits for adaptation, mitigation and biodiversity.

Various climate change impacts directly or indirectly affect the agriculture sector (crop and livestock production) in Europe. The report addresses part of the agriculture sector (crop yield and livestock and livestock commodities) and focuses on food and fodder production needs. It presents an overview of the main EU policies and programmes and gives examples of adaptation measures that have been successfully implemented in practice in most European countries and show the benefits of mitigating climate change and improving biodiversity. The report is based on reviewing the scientific literature, policy documents and case studies available in the European Climate Adaptation Platform (Climate-ADAPT) and through projects financed by various EU programmes, such as Horizon 2020, LIFE+ and Copernicus.

The agriculture sector in Europe

Agricultural land accounts for 40 % of total EU land. Agriculture and food-related industries and services provide over 44 million jobs in the EU, and 22 million people are directly employed in the sector itself. Because of a favourable climate, technical skills in the sector and the quality of its products, the EU is one of the world's leading producers and exporters of agricultural products. In recent years, agricultural income in the EU has shown a general improvement, mainly due to technological progress, leading to an increase in productivity. Of all EU economic sectors, agriculture is the most dependent on climate and thus very vulnerable to climate change.

Agriculture is also an important contributor to climate change through emissions of GHGs and air pollutants. Non-CO_2 GHG emissions from agriculture have declined since 1990; however, agriculture is still the largest contributor to total EU non-CO_2 GHG emissions. The sector accounts for around 10 % of all GHGs in the EU. Non-CO_2 emissions of methane (CH_4) emissions from enteric fermentation make up the largest share (38 %) of all GHG emissions in the sector. Emissions from the use of fertilisers, manure storage and livestock need to be reduced, which depends on the effectiveness of implementing key relevant EU policies, in particular the Land Use, Land Use Change and Forestry (LULUCF) Regulation (Regulation 2018/841). Good progress was made in reducing emissions between 1990 and 2016: GHG emissions from the agriculture sector decreased by about 20 %, thus contributing to achieving the EU goal for 2020 (of a 20 % reduction in the total EU GHG emissions). However, significant further effort is needed from the sector to achieve longer term objectives (for 2030 and especially for 2050). To achieve net zero GHG emissions in the EU by 2050, an increase in carbon sequestration will probably be needed in the agriculture and forestry sectors. Shifts in consumer patterns and diets (varying the consumption of meat, milk and egg products) can help to further reduce emissions from agricultural production. The required additional mitigation actions would need to be in line with adaptation and biodiversity goals and actions.

Opportunities for climate change adaptation: solutions offered by policies and programmes

Global climate policy and trade aspects

At the global level, various conventions and programmes address adaptation in the agriculture sector. These are also important drivers of policy action within the EU. The Paris Climate Agreement, the Sendai Framework for Disaster Risk Reduction and the United Nations Sustainable Development Goals aim to strengthen the ability of all countries to deal with the impacts of climate change and promote adaptation in sectors such as agriculture. Furthermore, the Food and Agriculture Organization of the United Nations programme FAO-Adapt supports adaptation in the agriculture sector by providing technical capacity and financial support to, in particular, least developed countries. Trade flows of agricultural commodities are relevant, since these can counteract product shortages, which may occur as a result of weather and climate extremes, by providing imports from unaffected regions where such products are still available. Trade allows the spread of new technologies or know-how, reducing production costs and enhancing food and fodder security. Thus, trade may be enhancing both adaptation and mitigation actions, although there are many aspects of trade, together with its links to climate action in the agriculture sector, that require better understanding and further research.

The EU strategy on adaptation to climate change and the common agricultural policy

The EU agriculture sector is highly regulated by EU policies, in particular the common agricultural policy (CAP). The EU adaptation strategy, adopted in 2013 and evaluated in 2018, is a key EU-level driver of adaptation. With its objective of mainstreaming climate change adaptation into actions in various sectors at EU level, including agriculture, the strategy aims to promote adaptation in the agriculture sector within the CAP. Climate change is included as one of the specific objectives in the CAP and thus promotes the implementation of technical measures for both mitigation and adaptation at farm level. The 2018 evaluation of the EU adaptation strategy showed that the strategy has achieved its objectives, but the specific actions to improve the resilience of the sector are still limited. Therefore, the agriculture sector in Europe is still one of the sectors most vulnerable to climate change impacts both inside and outside Europe.

Climate change is included as one of the specific objectives of the current CAP, promoting the implementation of technical measures for both mitigation and adaptation at farm level. The main EU programmes promoting and financing adaptation measures in the agriculture sector are the Member States and regional rural development programmes (RDPs) under the CAP. Under the RDPs, several adaptation measures are available, and the mainstreaming of climate change policies into sectoral policies has taken place and is co-financed by the European Agricultural Fund for Rural Development (EAFRD). However, the impact that the CAP has in addressing adaptation lies in the ambition of and its implementation by Member States. The Member States can develop thematic sub-programmes including climate change and offer concrete measures for financing the adaptation. Although most of the RDPs offer adaptation measures for the period 2014-2020, these measures are mostly linked to modernisation, such as irrigation efficiency, and less to measures that have wider environmental benefits (such as ecosystem-based adaptation). The latter are limited to a few Member States (e.g. Finland and Austria). The lack of diversity in the adaptation measures offered in the RDPs is in part due to the lack of involvement of adaptation experts in developing the programmes.

The new proposed CAP for 2021-2027 has adaptation as a clear objective, which could lead to Member States having to increase their financing of adaptation measures in the sector. Adaptation to climate change has been elevated to an objective, to be addressed through the strategic plans that Member States need to develop. With the proposed CAP defining the different objectives that Member States can address within their plans, adaptation to climate change as an objective faces significant competition for funding. While the proposed CAP offers more opportunities for investments in adaptation, the proposal can, in some cases, also be seen as a driver of maladaptation or hampering adaptation. For example, continued coupled support payments for cotton production in water-scarce Member States has the potential to further exacerbate over-exploitation of aquifers. In general, national agriculture policies have increased the areas of irrigation, and water saving is not always a priority. Under the new CAP proposal, minimum requirements for ensuring investment in water saving for irrigation are not defined; rather, the proposal stipulates that investments in irrigation are ineligible for financing if they are not consistent with achieving good status of water bodies in accordance with the EU Water Framework Directive (Directive 2000/60/EC). Additional factors that may still limit the uptake of adaptation measures at the farm level include the non-binding nature of such measures (i.e. their implementation is not mandatory), and a lack of resources for investment, political urgency to adapt, institutional capacity, access to adaptation knowledge and information from other countries. The new CAP 2021-2027 could increase the involvement of adaptation experts in drawing up plans and therefore lead to a greater number and variety of adaptation measures.

National adaptation strategies and plans and the agriculture sector

In mid-2019 28 European countries (25 EU Member States and three EEA member countries) had a national adaptation strategy in place and 17 (15 EU Member States and two EEA member countries) also had a national adaptation plan. Based on the 2019 reporting under the Monitoring Mechanism Regulation (MMR) Article 15 ([1]) all national adaptation strategies explicitly mention the agriculture sector as one of the priority sectors, outlining specific measures to adapt it. Twenty EU Member States prepared specific climate change impacts and vulnerability assessments for the agriculture sector and 13 Member States introduced specific adaptation measures in the agriculture sector at national and regional levels.

EU innovation and research programmes

To increase the understanding of adaptation in agriculture, projects under the EU innovation and research programmes have been developed. The EU LIFE+ programme can support adaptation at the farm level by providing specific and detailed climate change data and information through various services and projects. The EU Copernicus programme, through its Earth observation programme and services,

([1]) Information on Member States' national adaptation planning and strategies, outlining their implemented or planned actions to facilitate adaptation to climate change — reporting obligation for national adaptation actions.

supports adaptation in the sector by providing relevant information and data to advisory services and farmers.

A number of adaptation-specific projects have been financed under Horizon 2020 and LIFE+ programmes, but priority knowledge gaps have not yet been filled and new gaps have emerged. These knowledge gaps include the impacts of global trade agreements on European agriculture, the level of economic benefits of adaptation at farm level, the co-benefits of adaptation and mitigation measures, and understanding the links between climate change, agriculture, human health and well-being. Moreover, the monitoring and evaluation of all the various adaptation approaches under these instruments are essential to further increase the knowledge base on successful adaptation measures in agriculture in Europe.

Opportunities for climate change adaptation: adaptation measures at farm level

Measures at farm level are still largely extensions or intensifications of existing climate risk management or activities to enhance production, in response to a potential change in the climate risk profile. The adaptation needs and the actual implementation of actions depend on the specific climate impact, the farm's economic situation, the size of the farm and the cultural background and education of the farmer. There are opportunities for implementing a wide variety of existing and proven measures at farm level that aim to improve the management of soils and water, which can provide benefits for adaptation, mitigation, the environment and the economy. The objectives of these potential measures are therefore to sustain resilient production, conserve soil and water resources, reduce pests, droughts and other weather and climate threats, as well as to reduce emissions or sequester carbon (Table ES.1).

The way forward

Improving a shared understanding of climate-related risks in the agriculture sector can open up a wider array of responses and solutions. Capacity building and education are important measures to mitigate and adapt to climate change and to influence consumers' behaviour in a way that ensures greater sustainability in the future. More sustainable diets and reducing food losses would contribute to this.

Adaptation has been elevated to an objective within the CAP; however, in terms of expenditure, Member States have tended to prioritise mitigation efforts over adaptation. To ensure that adaptation is adequately included in national strategic plans, the policy framework should require Member States to offer measures with a direct link to adaptation.

There is already a common understanding of the co-benefits of some measures, and there are EU innovation programmes in place that contribute to further increasing the knowledge base on successful adaptation measures in agriculture in Europe. To ensure proper uptake of adaptation measures, farm advisory services on adaptation actions are essential, making use of the growing availability of climate information.

Greater efforts are needed to increase the uptake of measures at farm level by promoting their win-win aspects for farmers, in terms of economic benefits, and for the environment, in terms of enhancing resilience and adaptive capacity. Adaptation measures need to be framed not as additional requirements but as solutions to enable farming in Europe to be sustainable in the long run. Making food production and trading environmentally sustainable and more resilient to climate change is possible, but it will require a major shift in public attitude, policies and knowledge.

Table ES.1 Summary of adaptation measures at farm level with positive effects on mitigation and biodiversity

Adapted crops	Using adapted crops could reduce the impact of extreme weather (e.g. frost) and climate events (e.g. droughts). This measure has synergies with mitigation in that soil carbon storage can increase. Introducing new crops or bringing back heritage crops has positive effects on biodiversity and ecosystem services and increases the genetic diversity of species, which in turn can become more resilient to extreme weather and climate conditions.
Use of cover crops and artificial soil covers	Cover crops and artificial soil covers can significantly reduce the risk of soil degradation exacerbated by climate change. The use of cover crops and artificial soil covers can also reduce the amount of nitrogen fertilisation required, and in turn the emissions of nitrogen not used by preceding crops, which can decrease nitrate leaching. Cover crops can improve wildlife habitats and diversity by decreasing erosion. The use of artificial soil cover should be limited to recyclable materials to limit waste disposal.
Crop diversification and rotation	Crop diversification and rotation improve the resilience of crops and deliver a range of ecosystem services (efficient nutrient cycling, conservation of biodiversity and improved soil quality). A long crop rotation provides more resilience against climate change, ensuring environmental benefits, including low GHG emissions.
No tillage and minimum tillage	No tillage or minimum tillage results in positive changes in soil properties, which has a significant impact in terms of increasing soil moisture. Carbon storage in the uppermost soil layers can increase. It also improves food supplies for insects, birds and small mammals due to crop residues and weed seeds being more available. The use of this measure depends heavily on the soil type and quality of the site, as some soils do not respond well to no tillage or minimum tillage (e.g. heavy clay). No tillage leads to an increasing need for either pesticides or alternative pest control (e.g. integrated pest control management).
Adapted timing of sowing and harvesting	Modifying the timing of sowing and harvesting can make use of better soil moisture conditions. Soil carbon storage can be increased as a result of higher yields. Adjusting cultivation timing to changed climatic regimes improves the quality of the yields.
Precision farming	Precision farming (i.e. using on-farm modern technology, using satellite data and tools for precise navigation) enhances the efficient use of inputs, such as fertilisers and pesticides, and can reduce water use and maintain soil structure. This measure requires investments in new machinery and the knowledge to use the new technologies.
Improved irrigation efficiency	Improved irrigation efficiency, rainwater harvesting and water reuse decreases water abstraction. It can enhance carbon storage in soils through increased yields and residues and can improve water quality, soil ecosystems and soil biodiversity.
Livestock breeding	Methane emissions can be reduced by feeding livestock more concentrates, normally by replacing forage; however, feeding livestock concentrates may be risky for animal health and can lead loss of biodiversity. Breeding livestock for greater tolerance to heat and increased productivity may have beneficial impacts on climate-regulating services, water and soil ecosystem services, and above-ground and soil biodiversity.
Improved pasture management	Improved pasture and grazing management helps to reduce degradation patterns and soil erosion by water and wind, increase biomass in grasslands and create more sustainable livelihoods for herders. Introducing grass species with higher productivity can accelerate atmospheric carbon sequestration in soils. However, adding nitrogen often stimulates nitrous oxide emissions, and increased irrigation may require more energy. Improved grasslands and pastures may have beneficial impacts on climate-regulating services through carbon sequestration.
Organic farming	Using organic fertilisers in organic farming promotes organic carbon storage in soils. Organic farming practices generate high levels of soil organic matter. This enhances water storage capacities and increases resilience against droughts and floods.
Improved livestock rearing conditions	Improving in-house animal rearing conditions (shading and sprinklers, ventilation systems) improves conditions for livestock production. Improving animal rearing conditions leads to decreased levels of methane emissions.
Farm production and income diversification	Diversifying farm income activities can serve as an important farm risk management strategy. Mixed production systems in farms can increase land productivity and efficiency in the use of water, fertilisers and other resources through recycling. In addition, diversifying production can decrease soil erosion.

1 Introduction

Key messages

- EU farmers produce one eighth of the global cereals output, two thirds of global wine production, half of global sugar beet output and three quarters of the world's olive oil.
- Agriculture is the economic sector most exposed to changes in climate patterns, with impacts highly specific to crop selection (and thereby location).
- Agriculture is an important contributor to climate change through emissions of greenhouse gases and air pollutants (such as ammonia and particulate matter).
- Climate change has a cascading effect on agro-ecosystems and agricultural production, as well as on the price, quantity and quality of the products.

1.1 Setting the scene

Agriculture provides food, services and resources and guarantees the livelihood of millions of people worldwide. In the EU alone, 22 million people are directly employed (part-time included) in the farming sector — up to 44 million people rely on the wider food sector (farming, food processing and retail/services). Agriculture is one of the most climate-dependent socio-economic sectors, since most of the agriculture productivity and quality are directly dependent on different climatic factors (McArthur, 2016). Climate change is already affecting agriculture, with effects unevenly distributed across the various regions of the world and within Europe (EEA, 2017b, 2018h; Ciscar et al., 2018; IPCC, 2019, 2018, 2014b).

Adaptation to climate change is widely recognised as a fundamental response to climate change for society for the next few decades. Adaptation is especially important for sectors such as agriculture, as it has important socio-economic implications for society and food security. This is reinforced by the Paris Agreement, which underlines the fact that adaptation measures need to implemented in synergy with mitigation action, and it is emphasised that food production systems need to be less vulnerable to the adverse impacts of climate change (UNFCCC, 2015).Therefore, the implications of the Paris Agreement for food and agriculture are significant. Explicit reference is made to food security and food production, highlighting 'the fundamental priority of safeguarding food security and ending hunger, and the particular vulnerabilities of food production systems to the adverse impacts of climate change'. Reference is also made to the need to 'increase[ing] the ability to adapt to the adverse impacts of climate change and foster climate resilience and low greenhouse gas emissions development, in a manner that does not threaten food production'. The ambitious 1.5 °C goal offers some prospects for food security. The agreement also emphasises that agriculture is an important sector in which the reduction of emission is possible while giving governments the freedom to decide exactly which emission sources to address (OECD, 2018).

Current intensive agricultural production and food systems are unsustainable from a natural resource perspective and can cause land degradation, nutrient losses and loss of biodiversity, contribute to decreased water quality and water scarcity, and ultimately contribute to emissions of greenhouse gases (GHGs) and air pollutants, which in turn contribute to climate change (UNEP, 2016). At the same time, the agriculture sector (as well as the forestry sector) offers opportunities for carbon storage, depending on management approaches (e.g. through cover cropping, conservation tillage, rotational grazing) and climatic conditions (Zomer et al., 2017).

Food, water and climate are three prominent elements in Sustainable Development Goals (SDGs) 2, 6 and 13, respectively. At a global level, the food system needs to be improved to achieve the range of SDGs included in the 2030 agenda for sustainable development (UN, 2015b). Eradicating hunger by 2030 requires more sustainable food production systems and climate-resilient agricultural practices, which also offer active solutions to decreasing the negative effects of climate change (UNFCCC, 2015). Making food production and trading environmentally sustainable and thereby more resilient to climate change is possible, but it will require a major shift in public attitude, policies and knowledge (EEA, 2017c).

1.2 The agriculture sector in Europe

Agriculture in Europe produces a range of food, feed and residual biomass products and provides other important functions, such as managing landscapes, rural development and tourism. Agricultural production can be categorised into three main elements (Gurria et al., 2017; Eurostat, 2016):

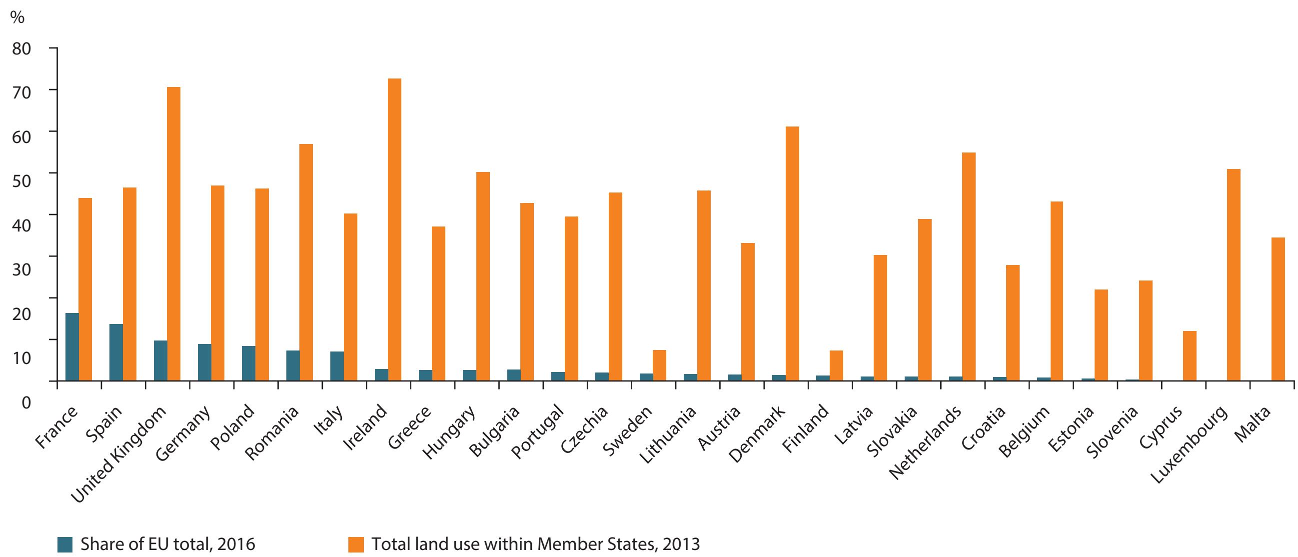
- agricultural crop production in the form of grains, roots, fruits and tubers and associated crop residues in the form of straw, chaff, husks, etc.;
- grazed biomass used as feed for livestock; and
- livestock production.

Biomass is also used for energy production purposes, mainly in the transport sector. Ethanol is mainly produced from wheat, maize and sugar beet, whereas more than 50 % of biodiesel consumed in the EU (based on 2014 data) is produced from rapeseed (EC, 2017c). Biodiesel is, to a lesser extent, also produced from waste oils and fats, but the overall share of biodiesel produced from these products has significantly increased since 2010 (EC, 2017c). More than 60 % of biodiesel and more than 90 % of bioethanol consumed in the EU is produced from EU feedstock, with the rest coming from sources outside the EU. The 2015 Indirect Land Use Change Directive (Directive EU 2015/1315) limits the share of biofuels from crops grown on agricultural land to 7 % by 2020 to ensure that biomass production for renewable energy does not negatively compete with food production and increase the loss of biodiversity (EEA, 2017f, 2017c).

In 2016, agriculture covered about 40 % of EU land (Eurostat, 2018c). The total share of agricultural land cover within EU Member States varies significantly. Whereas in the United Kingdom and Ireland agricultural land cover is 69 % and 72 % of the total, respectively, in Finland and Sweden the share is only 8 % and 7 %, respectively (Figure 1.1). Although agricultural land cover in France represents 16 % of the total utilised agricultural area (UAA) in the EU, it represents less than 50 % of total land cover within the country. Conversely, while agricultural land cover in Ireland represents only 2.9 % of the total UAA in the EU, it is significant within the country, totalling 72.5 %.

The majority of agricultural land is non-irrigated arable land (46%), followed by grassland pastures (18 %) and agricultural land with significant areas of natural vegetation (16 %) (EEA, 2017f, 2017c). Agricultural land is largely concentrated in four Member States: France (16 %), Spain (14 %), the United Kingdom (10 %) and Germany (9 %) (Eurostat, 2018c) (Figure 1.1). Poland,

Figure 1.1 Share of utilised agricultural area in EU Member States



Note: Percentage of total UAA in the 28 EU Member States (EU-28) (blue) and percentage of total UAA within Member States.

Source: Eurostat (2018c).

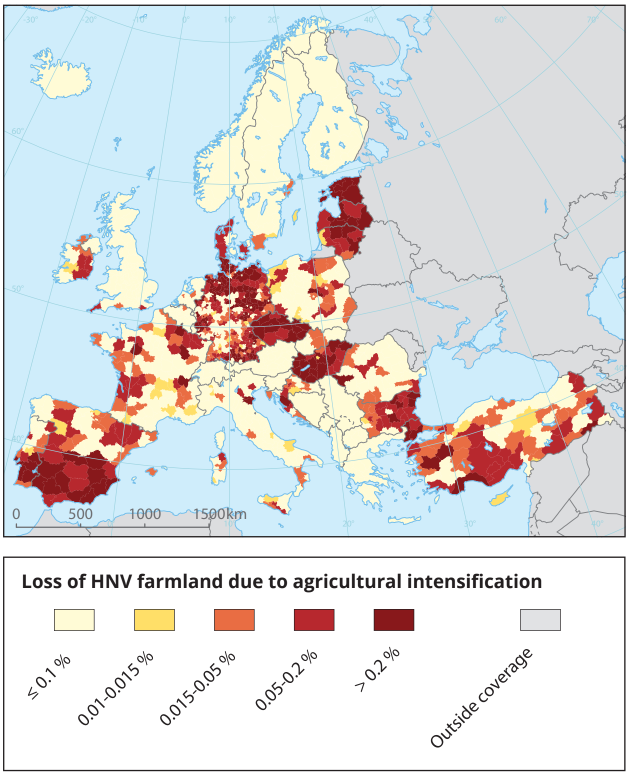
Romania and Italy comprise about 22.7 % of agriculture cultivation. Less than one third (28.6%) of the land cultivated for agriculture is found in the rest of the Member States.

The total organic farming area ([2]) in the EU-28 was 11.9 million ha in 2017 (Eurostat, 2017b). The UAA under organic production increased by 18.7 % between 2012 and 2016. The share of total organic area as a percentage of the total UAA was 6.7 % in 2016. The share of organic farming is greatest in Austria, followed by Estonia and Sweden (Figure 1.2).

High nature value (HNV) farmland is defined as hot spots for biodiversity in rural areas characterised by extensive farming practices. Farming in Natura 2000 (N2K) areas is also associated with extensive practices, and farmland makes up around 40 % of the total area included in the N2K network (EC, 2017e). N2K sites around 10 % of the total agricultural land of the EU-28 (EC, 2017f). HNV farming is decreasing in Europe, in part due to the intensification of agriculture (Map 1.1).

Both organic and HNV farming, with its extensive, traditional agro-systems, produce a high environmental value and unique landscapes. Such practices, including low or minimal tillage, crop rotation and reduced fertilisation, present an important opportunity for climate adaptation (see Chapter 5). Increasing resilience to the effects of climate change can be

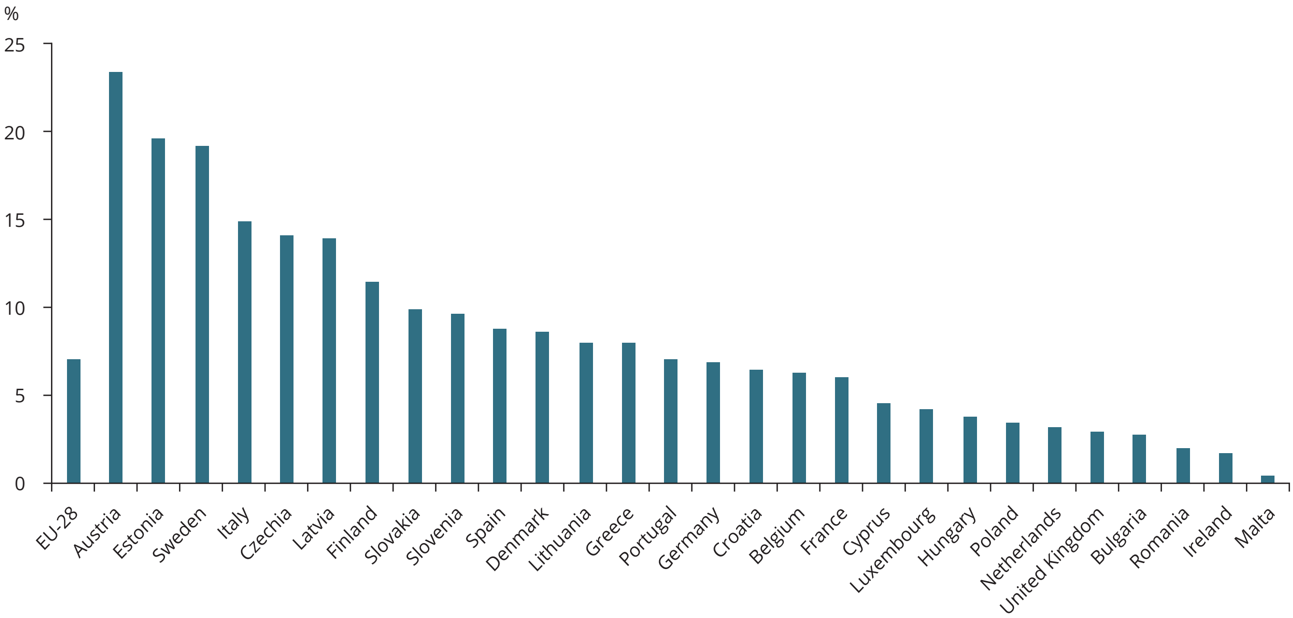
Map 1.1 Loss of high nature value farmland due to agricultural intensification



Note: Loss is presented as percentage of total area in NUTS 3 (Nomenclature of Territorial Units for Statistics) regions based on Corine land cover changes 2006-2012.

Source: Based on EEA (2017e).

Figure 1.2 Share of organic farming in EU Member States

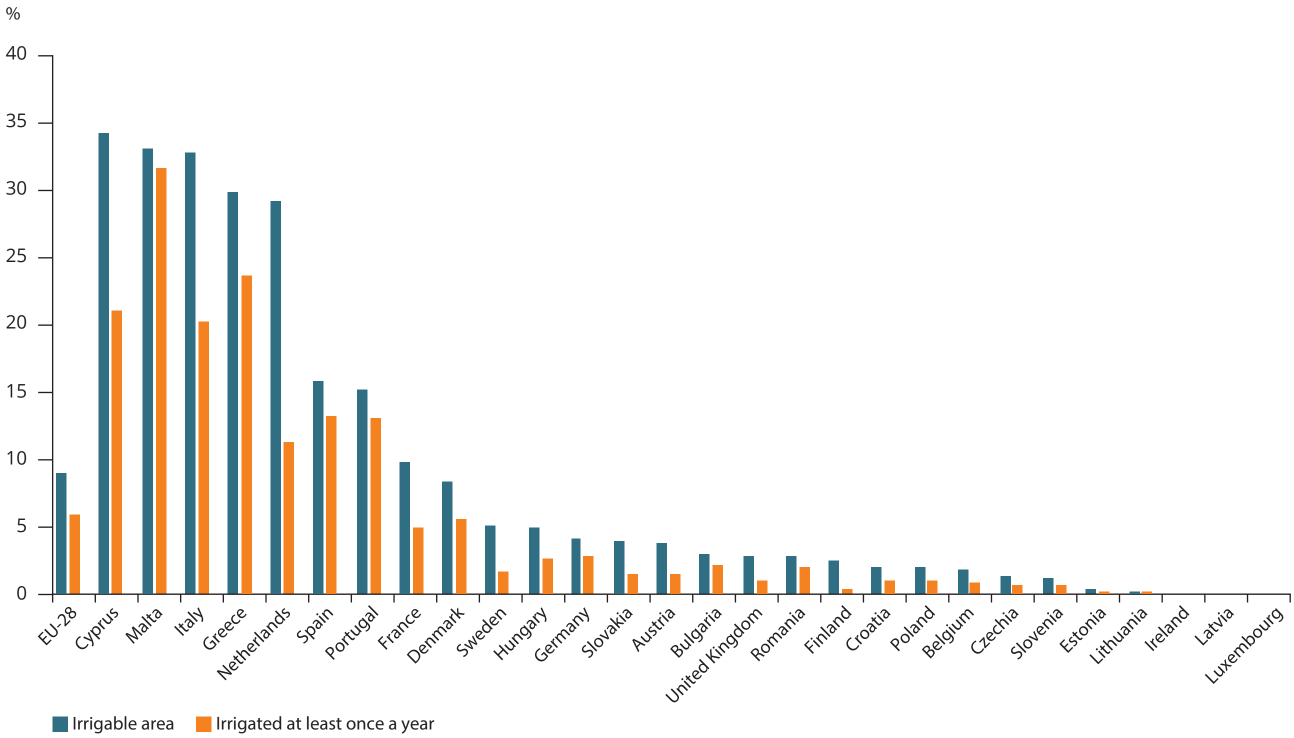


Note: The shares are presented as percentages of the UAA, based on 2017 data.

Source: Eurostat (2018b).

([2]) The total organic area is the sum of the 'area under conversion' and the 'fully converted area'.

Figure 1.3 Share of irrigable and irrigated utilised agricultural area



Notes: Share of the irrigated and irrigable area of total UAA in the country in percentages. Irrigable area is the area that is equipped for irrigation, while the irrigated area measures the actual amount of land irrigated. Data are based on 2013 survey.

Sources: Eurostat (2018c)

achieved through organic and HNV farming practices that emphasise crop diversity (e.g. through rotation), and landscape elements such as field margins can reduce pest outbreaks, plant and animal diseases and support the improved use of nutrients and water (Smith et al., 2011).

The agriculture sector is a significant user of freshwater resources in Europe. In 2015, the agriculture sector accounted for around 25 % of total water abstraction in Europe (EEA, 2018i). Freshwater use for agriculture in Europe is the largest in southern Europe (due to the dry climate), where abstraction for agriculture in the period 2010-2015 accounted for 55 % of total abstraction (EEA, 2018i). The share of agricultural land under irrigation varies among Member States, with a higher share of agricultural land under irrigation systems in southern Europe than in northern and western Europe (Figure 1.3). Climate change projections show that parts of Europe (especially southern Europe) will experience less precipitation and more frequent and severe drought events in the future, making water even less available to the sector (see Chapter 4).

1.3 Changes in agricultural productivity

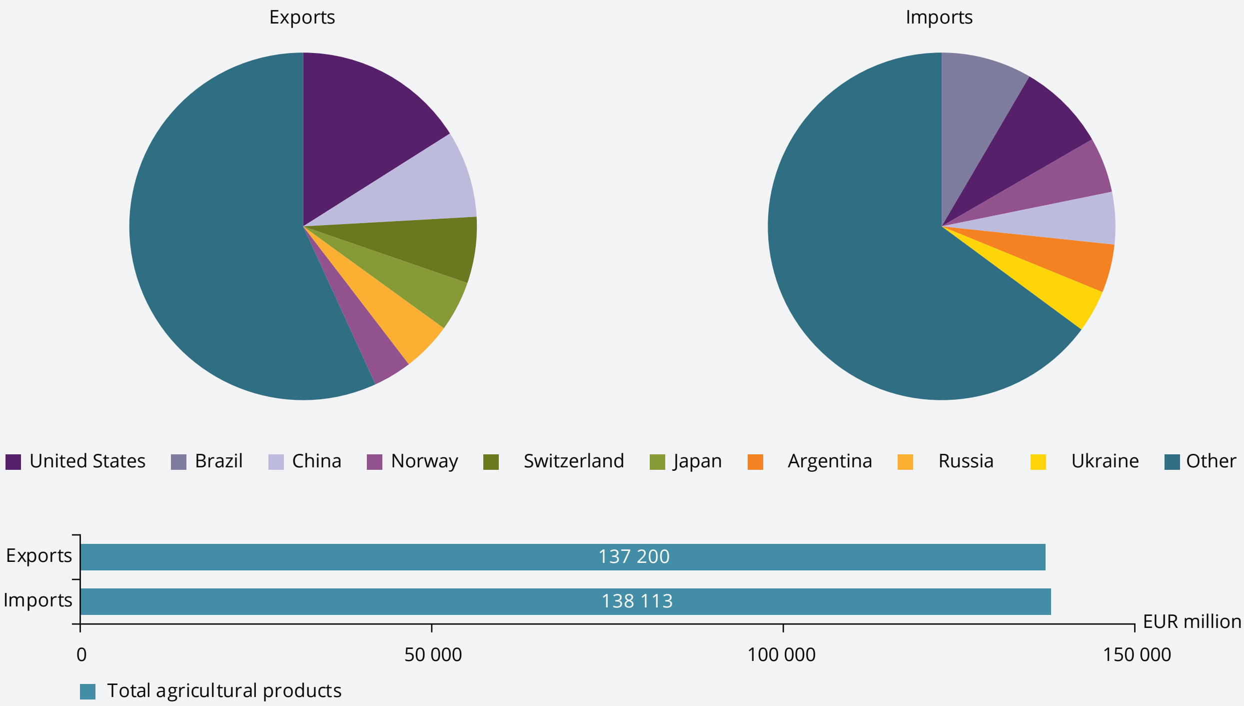
The productivity of European agriculture has increased significantly since 1950, mainly as result of intensification and specialisation (EEA, 2015d). Regional differences between productivity in eastern and western Europe still remain. Between 2011 and 2013, agricultural labour productivity in eastern Europe was only 19 % of the output from western Europe (Vanschoenwinkel et al., 2016).

EU farmers produce one eighth of the global cereals output, two thirds of the global wine production, half of the global sugar beet output and three quarters of the world's olive oil (EEA, 2015d, 2017c). The EU is one of the largest agri-food exporters worldwide (EC, 2016a). Agricultural exports from the EU-28 Member States amounted to around EUR 138 billion in 2017, with imports amounting to just over EUR 117 billion (EC, 2018a). The output of the EU agriculture sector was estimated at EUR 427 billion in 2017, and agricultural trade (value) comprises 7.5 % of total exports and 6.6 % of total imports (EC, 2018a). The top exported products in Europe in 2014 were

Box 1.1 Current trade dynamics in the EU

Trade in agricultural commodities between the EU and the rest of the world has been rising (EC, 2018f). Moreover, trade within EU Member States has increased more than 100 % in recent decades (Eurostat, 2018a). As a result, the value of trade in agricultural products has increased in the last between 1998 and 2017, with exports (increased by 6.2 %) growing faster than imports (increased by 4.7 %). Major EU-28 exports to countries outside EU relate to foodstuffs (processed goods deriving from vegetable and animal products) while most of the imports relate to vegetal products (e.g., trees, plants, vegetables, fruit, coffee, cereals, seeds and oil). European and international trade in crops will likely continue to increase due to rises in both global demand and consumption within the EU. The biggest trading partners are United States, China and Brazil (Figure 1.4).

Figure 1.4 Share of exports and imports of agricultural products by main partner between EU-28 and other countries in 2017



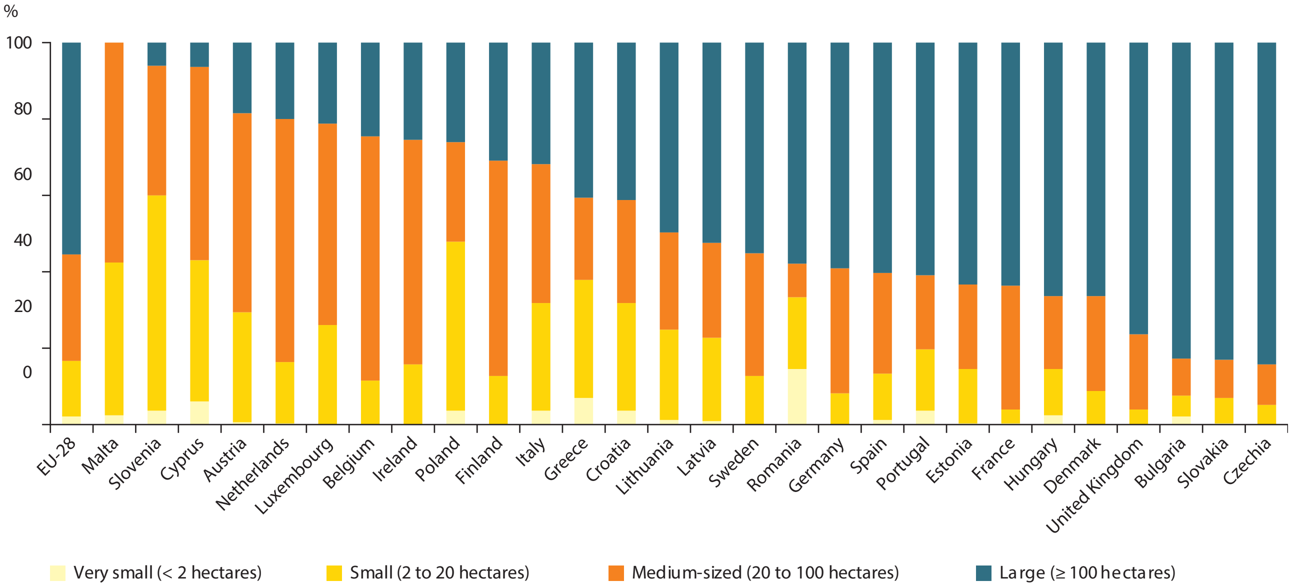
Note: The pie charts present the breakdown of share of exports and imports between the EU and its main trading countries. Total amount of exports and imports is presented in the bars below.

Source: Eurostat (2018a).

'wine, cider and vinegar' and 'spirits and liqueurs' (each 8 % of total EU agri-food exports), mainly exported to United States markets, and wheat, 'infant food and other cereals' (each 5 % of total agri-food exports), mainly exported to North African countries, China and Russia (EC, 2015a). EU imports comprise mainly three types of product: fruit, nuts and spices, vegetable proteins and fats, and coffee. The main import partners are the United States, Brazil, Argentina, China and Norway (Box 1.1).

The gross value added to basic prices of the EU-28's agricultural industry in 2018 was estimated at around EUR 180 billion, while subsidies for production amounted to around EUR 50 billion (Eurostat, 2019). Direct payments under the EU common agricultural policy (CAP) make up around 46 % of the EU's farming income (EC, 2017b). In many cases, subsidies are an important mechanism that reduces farmers' loss of income due to extreme weather and climate events and time gaps between consumer demand and

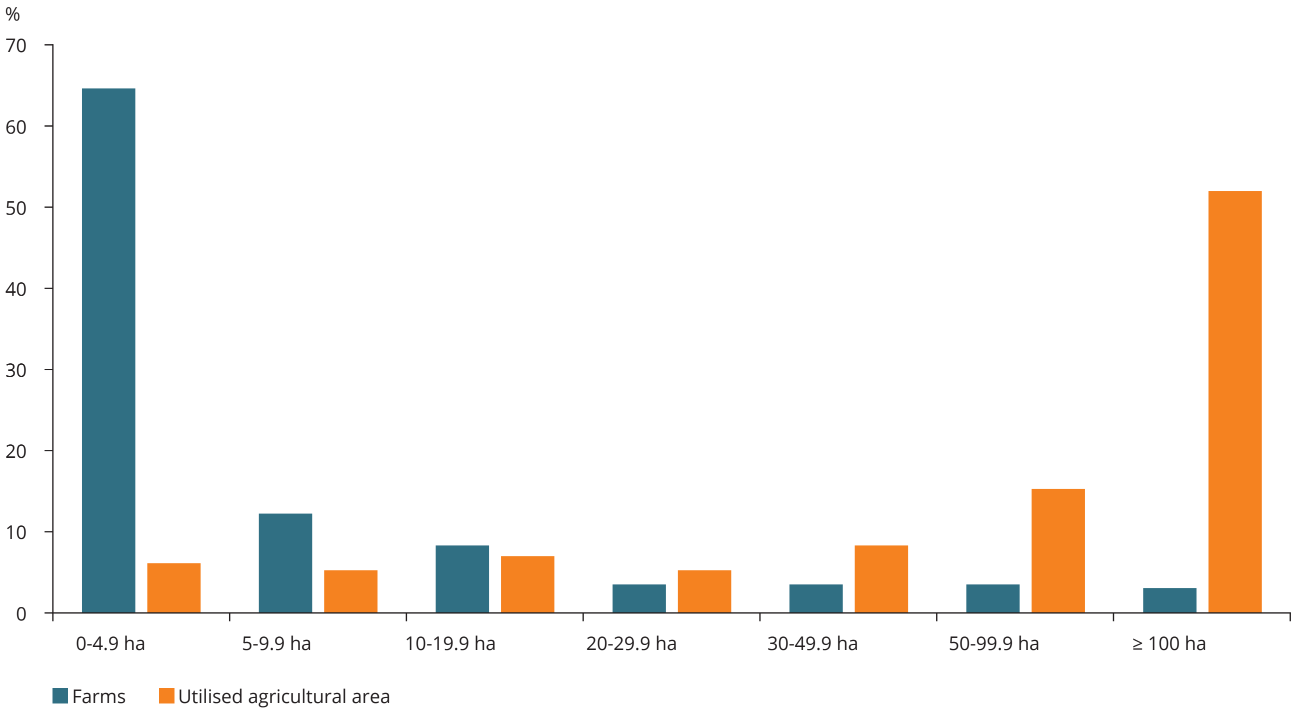
Figure 1.5 Share of farms by farm size



Notes: Share of total utilised agricultural area (UAA) by the physical size of farms. Four different classes have been defined according to their size: very small; small; medium-sized and large.

Sources: Eurostat (2017b)

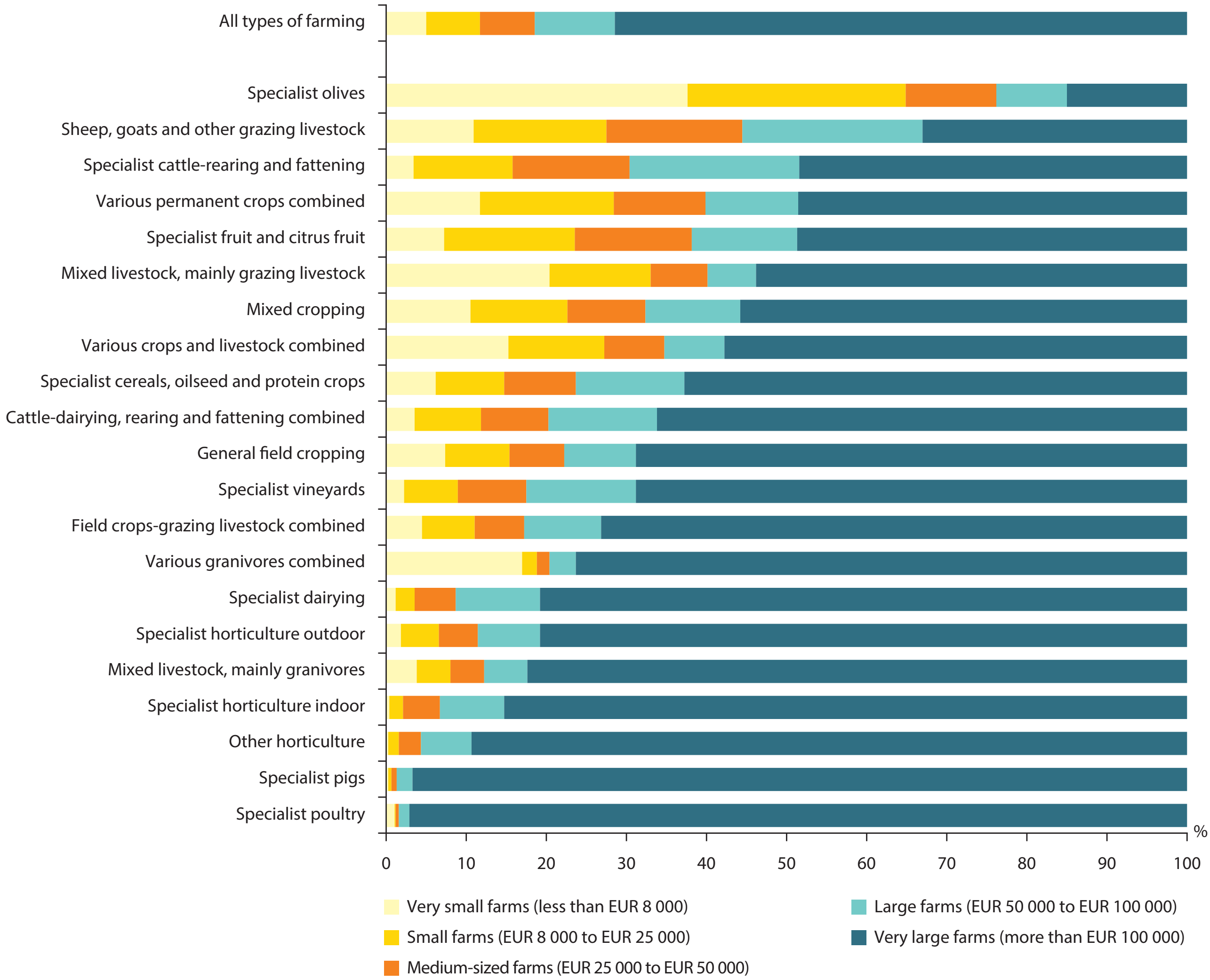
Figure 1.6 Distribution of number of farms and size per farm in the EU



Note: Share of farms and farmland (in terms of UAA) in the EU based on size (%).

Source: Eurostat (2017b).

Figure 1.7 Share of economic size of farm per farm type



Note: Based on the EU-28 from 2013 data. The economic size of the farm is the average monetary value of the agricultural production of the farms.

Source: Eurostat (2017b).

farmers being able to supply the products. At the same time, EU subsidies for the agriculture sector are linked to higher GHG emissions and nutrient surpluses than scenarios without direct payments (Brady et al., 2017).

Alongside the increase in productivity, farm sizes have increased across the EU, while the number of farms has declined. Small farm holdings dominate the agriculture sector in Europe.

Between 2013 and 2016, the total number of farms declined from 10.8 million farms in 2013 to 10.3 million farms in 2016 (Eurostat, 2017b). Some of the largest reductions in the number of farms were recorded among those Member States that joined the EU in 2004, or more recently, as a process of structural adjustment took place. The average size of a farm still varies widely among Member States In 2016, at least 65 % of EU farm holdings were less than 5 ha in size ([3]), and large and very large farm holdings (above 50 ha) accounted for only around 7 % of all farms (Eurostat, 2017b) (Figure 1.5). However, these large farms used a little more than two thirds (68%) of the total UAA in the EU-28 (Eurostat, 2017b) (Figure 1.6). Such farms are devoted to the following activities: horticulture; specialist dairying; and specialist pig farming (Figure 1.7). The only exception was specialist olive farming, in which very small and small farms accounted for 39.4 % of the UAA, compared with 35.7 % for large and very large farms (Eurostat, 2017b). More than three quarters of all livestock units were reared on very large farms in half of the Member States, with this share peaking at over 90 % in Belgium, the Netherlands and Denmark.

([3]) The EU Farm Structure Survey counts only farms with a minimum size of 5 ha.

Map 1.2 **Main climate change impacts on the agriculture sector for the main biogeographical regions in Europe**

Coastal zones
Sea level rise
Intrusion of saltwater

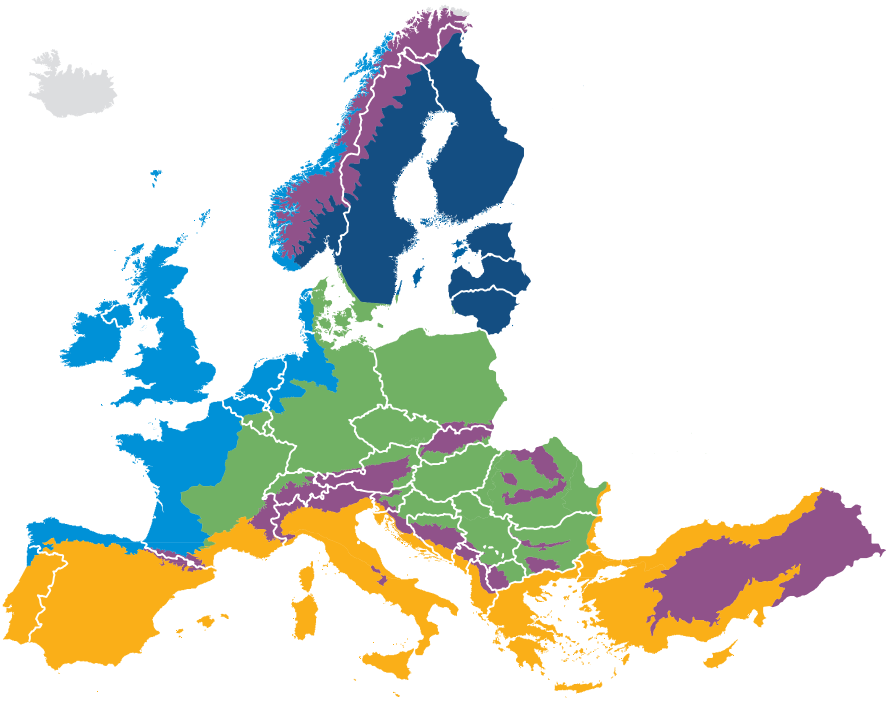
Mediterranean region
Large increase in heat extremes
Decrease in precipitation
Increasing risk of droughts
Increasing risk of biodiversity loss
Increasing water demand for agriculture
Decrease in crop yields
Increasing risks for livestock production
Agriculture negatively affected by spillover effects of climate change from outside Europe

Boreal region
Increase in heavy precipitation events
Increase in precipitation
Increasing damage risk from winter storms
Increase in crop yields

Atlantic region
Increase in heavy precipitation events
Increasing risk of river and coastal flooding
Increasing damage risk from winter storms

Continental region
Increase in heat extremes
Decrease in summer precipitation
Increasing risk of river floods

Mountain regions
Temperature rise larger than European average
Upward shift of plant and animal species
Risk of hail
Risk of frost
Increasing risk from rock falls and landslides



Source: Adapted from EEA (2017b).

Although structural changes have taken place, there is still a high share of semi-subsistence farms in many Member States that joined after 2004 (e.g. Romania, Croatia, Hungary, Bulgaria and Latvia). The adaptive capacity — that is, the ability to adjust to potential damage, take advantage of opportunities or respond to consequences — of semi-subsistence farms can be limited because of a lack of financial resources and human capacity (IPCC, 2014b, 2018). Policy options targeted at this subset of the farming community are important for reducing small farms' vulnerability to climate change impacts.

In the period 2000-2017, the estimated decrease in the area of arable land was 5 %, grassland 1 % and permanent crops 1 %. In total, the loss of UAA for the EU-24 (excluding Sweden, Finland, Croatia and Malta) for built-up areas can be estimated at around 80 000 ha/year. The loss of UAA has reduced compared with previous years. From 2010 to 2015, the decrease in UAA was 0.3 %/year, compared with 0.8 %/year between 2005 and 2010 (EC, 2016a). This trend will continue to decrease, with an estimate d loss in UAA of 0.2 %/year until 2026.

Loss of agricultural land is mainly attributed to land abandonment and the expansion of artificial areas (i.e. roads, buildings, etc.) (EEA, 2017e). The loss of UAA due to soil sealing poses a risk to the ecosystem's resilience to climate change impacts, for example the ability to cope with floods due to loss of land area for water retention, and reduces the effective delivery of ecosystem services, such as important mitigation needs like carbon retention (EC, 2016b; EEA, 2015b).

1.4 Climate change and agriculture

Changes in mean temperature and precipitation as well as weather and climate extremes are already influencing crop yields and livestock productivity in Europe. These impacts can be either positive or negative, according to the species and geographical regions, and depending on a variety of factors, such as physical impacts (determined by changes in temperature, precipitation patterns and atmospheric CO_2 concentration), changes in agro-ecosystems (loss of pollinators and increased incidence of pests and diseases) and the adaptive responses of human systems (FAO, 2016; EEA, 2017b). Agriculture also contributes to climate change through the release of greenhouse gases (GHGs) and air pollutants.

Combined effects of changes in temperature, rainfall and atmospheric CO_2 concentration influence crop yields and impacts differently across European regions (Map 1.2). Potential positive effects related to increased temperatures are expected mostly in northern Europe, while a reduction in crop productivity and an increased risk for livestock are projected in large parts of southern Europe (EEA, 2017b). Climate projections show that most of Europe will experience higher levels of warming than the global average; however, strong differences are expected across the European regions for global warming of 2 °C as well as for 1.5 °C warming (IPCC, 2018) (Table 1.1).

1.5 Climate change and cascading effects in the agriculture sector

Climate change can directly and indirectly impact agricultural production and the agro-ecosystems ([4]) upon which they rely. Direct impacts relate to changes in phenology and calendars, displacement of cultivation areas and soil loss, changes in water supply and irrigation demand, and direct effects of increased levels of CO_2 on growth. Indirect effects are those that arise as a result of direct effects that can have further negative impacts on agricultural production, for example increases in pests, diseases, invasive species and extreme events, such as very strong winds, hailstorms, intense heat and frosts. Impacts on agricultural production can lead to economic and social impacts related to livelihoods linked to the farming sector and food security. Given this, there is a cascade of impacts from climate change that affect agro-ecosystems and agricultural production, and in turn influence the price, quantity and quality of products, and consequently trade patterns, agricultural income and food prices (Figure 1.8). At the global scale, these cascading impacts affect food security and nutrition, mainly for people who directly depend on agriculture for their food and livelihood (FAO, 2016).

Table 1.1 Summary of main risks for agriculture associated with global warming of 1.5 °C and 2 °C scenarios

Physical climate change drivers	Nature of risk	Global risks at 1.5 °C of global warming above pre-industrial levels	Global risks at 2 °C of global warming above pre-industrial levels	Change in risk when moving from 1.5 °C to 2 °C of warming	Confidence in risk statements	Regions where the change in risk when moving from 1.5 °C to 2 °C are particularly high
Heat stress, water stress, droughts	Changes in ecosystem production	M/H	H	Large increase	M/H	Mediterranean basin
Heat and cold stress, water stress, heavy precipitation, droughts	Shift and composition change in biomes (major ecosystem types)	M/H	H	Moderate increase	L/M	South eastern Europe Central Europe
Heat stress, water stress, droughts	Shift and composition change of biomes (major ecosystem types)	M/H	H	Moderate increase	L/M	Mediterranean basin

Note: H is high; M is medium; L is low.

Source: Adapted from IPCC (2018).

([4]) Agro-ecosystems are here defined as a dynamic association of crops, pastures, livestock, other flora and fauna, atmosphere, soils, and water. Agro-ecosystems are contained within larger landscapes that include uncultivated land, drainage networks, rural communities and wildlife (EEA, 2019), based on US EPA Mid-Atlantic integrated assessment.

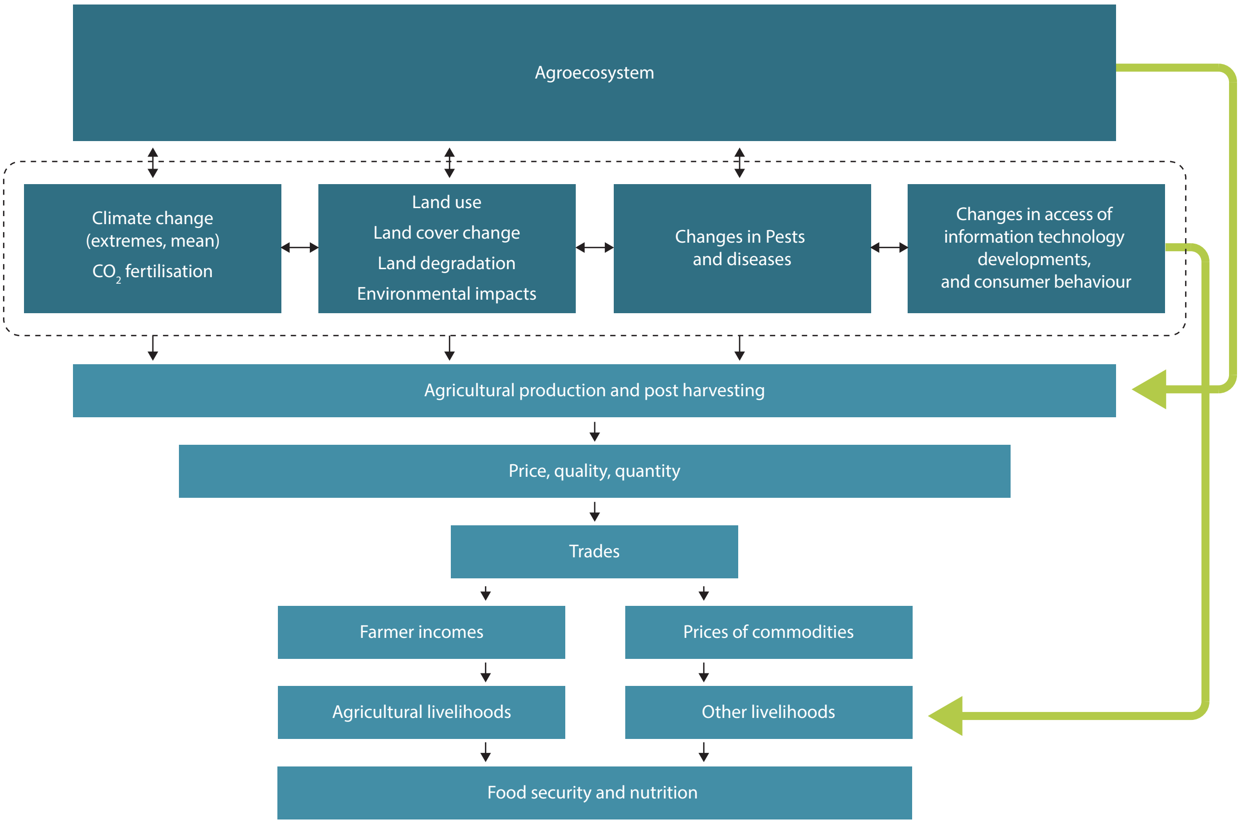
Socio-economic drivers, such as population growth, changing diets, biofuel production and changes in climate conditions, are expected to determine, among other things, new demands for food, higher food prices (Nelson et al., 2014a) and food price volatility (Porter et al., 2014) in the coming decades. The severity of the cascading impact depends on the source of the stress and the vulnerability of the system (or population) under stress (FAO, 2016). Consequently, the impacts are exacerbated or reduced at each stage according to the vulnerability and exposure of the system and its components. Food systems are complex systems, influenced by the biophysical context as well as the social and institutional context, and the interactions between the various components need to be considered to analyse future behaviour, changes and interactions throughout the system (Niles and Brown, 2017).

Europe is mostly negatively affected through price volatility and disrupted trade (EEA, 2017b). For example, increasing price volatility could lead to disruption in the supply of agricultural commodities that are mostly imported (Barnett et al., 2013). Similarly, changes in the price of animal fodder can affect meat production in Europe. The Mediterranean region in Europe has been identified as the most susceptible to shocks in the flow of agricultural commodities, owing to its relatively high dependence on food imports from regions outside Europe and the more prominent role of the food sector in its economy (Barnett et al., 2013).

1.6 Scope and outline of the report

This report provides an overview of climate change impacts and adaptation in the agriculture sector and addresses the links between climate change and the agriculture sector in Europe. It aims to contribute to a better understanding of the links between climate change and agricultural productivity in Europe. The focus is on crop farming and livestock, focusing on food and fodder production and mostly excluding aspects of agroforestry and agro ecology. The report assesses different types of literature, such as:

Figure 1.8 Schematic representation of the cascading effects



Note: The chain of cascading effects from climate change that impacts agro-ecosystems, agricultural production, market, trade and food security and nutrition. The green arrows represent direct impacts of changes in agro-ecosystems on agricultural production (through, for example, changes in agricultural practices) and impacts of drivers on livelihoods.

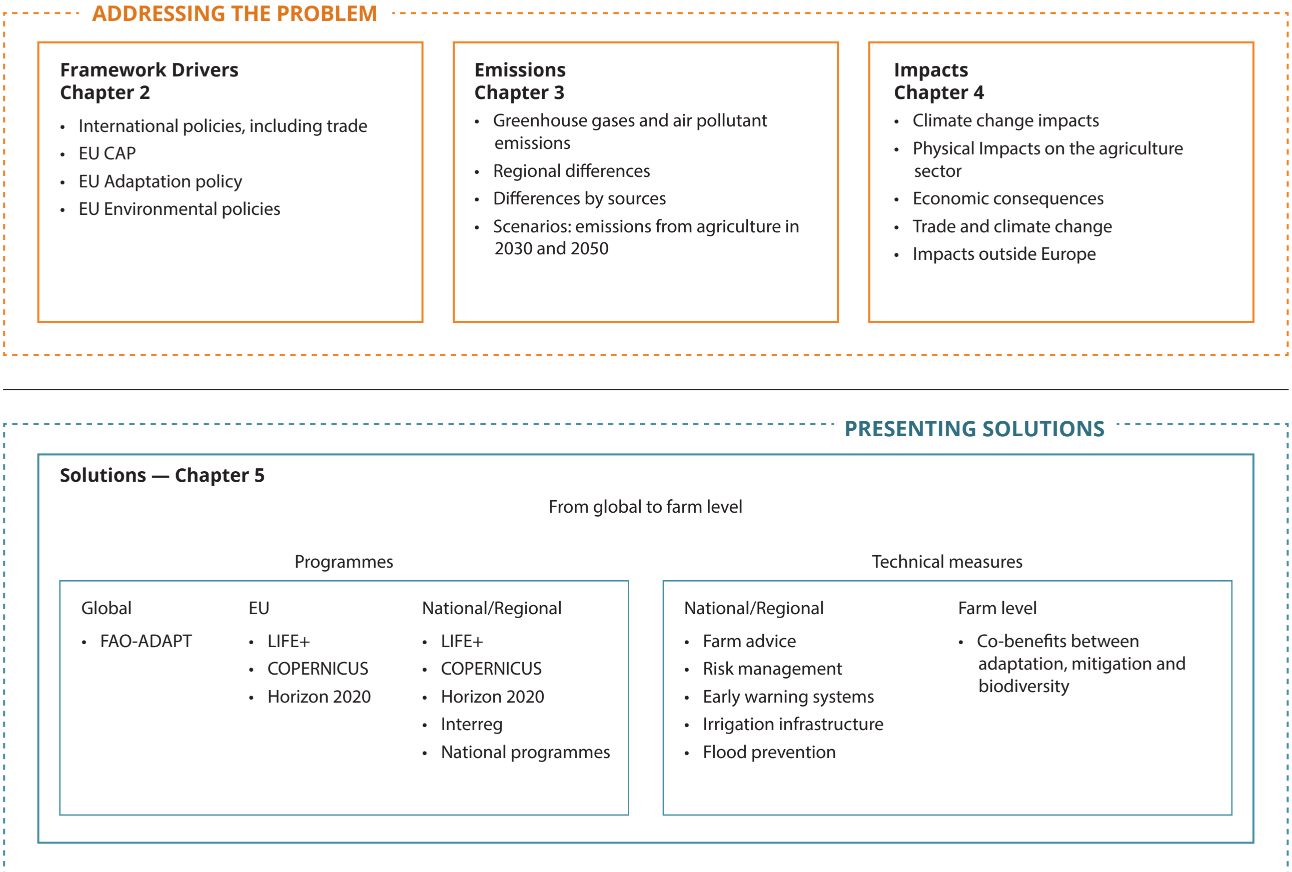
Source: Adapted from FAO (2016).

- EEA assessment reports and information from EEA member countries;
- scientific literature and outcomes from European research projects and initiatives on climate change and adaptation in Europe;
- outcomes of the studies prepared by the Directorate-General for Climate Action (DG CLIMA), the Directorate-General for Agriculture (DG AGRI) and the Directorate-General Joint Research Centre (DG JRC);
- relevant aspects of programmes such as the Joint Programming Initiative on Agriculture, Food Security and Climate Change (FACCE-JPI), Modelling European Agriculture with Climate Change for Food Security (MACSUR) and the Copernicus Climate Change Service (C3S);
- the Intergovernmental Panel on Climate Change (IPCC) AR5 report — *Climate change 2014: Impacts, adaptation, and vulnerability* (IPCC, 2014b) — and the IPCC special reports on the impacts of global warming of 1.5 °C above pre industrial levels (IPCC, 2018) and Climate Change and Land (IPCC, 2019).

This EEA report consists of six chapters and addresses the following elements, which in most cases are inter-connected (Figure 1.9).

- Chapter 1 is an introduction.
- Chapter 2 presents the main policy framework at international and EU level that drives, and potentially hampers, adaptation in the agriculture sector.
- Chapter 3 presents pressures arising from the sector on climate change by giving an overview of GHG between 1990 and 2016, air pollutant emissions between 2000 and 2016, and the outlook for the 2030s and 2050s.

Figure 1.9 Framework and structure of the report



Note: Chapters and main topics presented in each chapter. Chapters 2, 3 and 4 address the drivers of climate change and its impacts on the agriculture sector and Chapter 5 presents solutions for adapting the sector by considering the environment. Chapter 1 introduces the report, and Chapter 6 presents the way forward.

Source: EEA.

- Chapter 4 addresses key physical and economic impacts in Europe and outside Europe, with their effects on European agriculture.
- Chapter 5 describes solutions — programmes and measures — for adapting to climate change. It also addresses co-benefits with climate change mitigation and other socio-economic sectors, including biodiversity.
- Chapter 6 presents the way forward for policy developments and knowledge gaps.

1.7 Links to EEA activities

In recent years, the EEA has prepared various products on themes related to climate change and agriculture. These include climate change impacts on agriculture, agricultural contribution to climate change, emissions from agriculture in water, in air and on the land and links between agriculture and biodiversity, bio-economy, bio-energy and sustainable food production.

1.7.1 Climate change

The following EEA reports focusing on climate change impacts, vulnerability, adaptation and disaster risk reduction have been published:

Climate change, impacts and vulnerability (EEA, 2017b) presents trends and projections of around 40 indicators, with a focus on key climate variables and on impacts of climate change on health, environment and economy. The report specifically addresses impacts on the agriculture sector, in particular changes in growing seasons of agricultural crops, agro-phenology, water-limited crop yield and crop water demand and livestock systems. The report also addresses changes in extreme events (in particular heat waves, droughts, floods, forest fires, hail and frost), which strongly affect agricultural production.

Climate change adaptation and disaster risk reduction in Europe (EEA, 2017a) addresses the links between climate change adaptation and disaster risk reduction. The report presents the impacts of weather and climate-related hazards on human health, society and ecosystems and addresses how the negative impacts can be mitigated by enhancing the coherence between climate change adaptation and disaster risk reduction.

National climate change vulnerability and risk assessments in Europe (EEA, 2018d) provides a systematic review of national climate change impacts, vulnerability and risk assessments across Europe. The report shows that the national climate change impacts and vulnerability assessments cover 19 different sectors, and the agriculture sector, together with water management, is most frequently addressed in these national assessments.

Exploring nature-based solutions: The role of green infrastructure in mitigating the impacts of weather- and climate-related natural hazards (EEA, 2015b) highlights options for making ecosystems, including those linked to agricultural land use, more resilient to climate change impacts, such as flooding and storm surges, and considers the carbon storage capacity of ecosystems.

The EEA also regularly publishes annual reports on GHG and air pollutant emissions and energy.

1.7.2 Bio-economy and sustainable food production

In 2017, the EEA published a report assessing the food system in Europe and sustainable agricultural production (EEA, 2017c). The report addresses the European food system and analyses European production, consumption and trade of food and the associated environmental and human health aspects.

The 2018 report *the circular economy and the bioeconomy. Partners in sustainability* (EEA, 2018f) addresses the flow and use of biomaterials from agricultural production to consumers. The report explores possible synergies, conflicts, gaps and trade-offs between the bio- and circular economies' objectives and actions and other sectors, including agriculture. One of the key findings highlights that further expanding the bio-economy could shift land use and affect land availability for food production.

1.7.3 Biodiversity and ecosystems

The EEA has managed the Biodiversity Information System for Europe (BISE) and the European Nature Information System (EUNIS). It has contributed to the development of agri-environmental indicators ([5]), Streamlining European Biodiversity Indicators (SEBI2020), which includes the indicators on agriculture (e.g. SEBI019 — Agriculture: nitrogen balance — and SEBI020 — Agriculture: area under management practices potentially supporting biodiversity). In addition, the EEA report on green infrastructure and flood management (EEA, 2017d) presents how green infrastructure can be used for flood management and outlines the benefits for society and economic sectors (including the agriculture sector).

Furthermore, the EEA contributes to the regular reporting on the mapping and assessment of ecosystems and their services (MAES), which presents the conditions of terrestrial, freshwater and marine ecosystems (EC, 2016b).

1.7.4 Water management

The EEA assessment report on the status and pressures of European waters (EEA, 2012a) shows that a large proportion of the water bodies, particularly those in regions with intensive agricultural activity and a high population density, hold poor ecological status and are affected by pollution pressures.

The EEA report *Towards efficient use of water resources in Europe* (EEA, 2012b) presents an overview of measures of water efficiency. The agriculture sector has benefited from the shift towards water-efficient irrigation techniques, such as drip irrigation, altered crop patterns and wastewater reuse.

The EEA indicator 'European waters — status and pressures' (EEA, 2018i) indicates that the agriculture sector is a key driver, contributing to the less than good status of European water bodies. In certain parts of Europe, water bodies suffer from pollution by nutrients and chemicals thanks to agricultural practices. In other European regions, hydro-morphological alterations and over-abstraction are the most important pressures affecting ecological status. The impacts that agricultural activities have on water body status has the potential to make them less resilient to further impacts from climate change. Measures targeting water efficiency are essential for building resilience into our systems and adapting to climate change (EEA, 2012a).

1.7.5 Soils, land and forestry

Most EU food, feed and fibre production requires soil. Soil is also essential for ecosystem health and for mitigating climate change, since soil is a global carbon sink. The EEA updates information included in the indicators and assessments on soil moisture, soil organic carbon and soil erosion.

Agriculture is a major driver of land use and land cover change, which is in itself a component of land surface processes influencing climate regulation. The EEA report *Landscapes in transition* (EEA, 2017f) provides information on the drivers of the transitions that landscapes are currently going through, based on newly available data on land cover change in Europe.

One of the main drivers of land use changes and deforestation in Europe is the intensification of agriculture, which leads to the removal of small forest patches from formerly mosaic landscapes. The EEA report on European forest ecosystems (EEA, 2016) addresses the state of forests and presents the main environmental, economic and social pressures that challenge their sustainability.

([5]) http://ec.europa.eu/eurostat/web/agri-environmental-indicators

2 Policies on adaptation to climate change in agriculture

Key messages

- The 2018 evaluation of the EU adaptation strategy outlines how Europe is still vulnerable to climate impacts within and outside its borders. Among the four sectors assessed, the cross-border effects of climate change are the strongest in agriculture.
- International policies play a key role in highlighting the importance of adapting to climate change in the agriculture sector at a global level. In Europe, the EU adaptation strategy and the common agricultural policy offer opportunities for the EU agriculture sector to adapt to climate change; however, the ambition varies by EU Member State.
- Based on the results of the reporting under the Monitoring Mechanism Regulation in 2019, all Member States (out of those that reported) ([6]) explicitly identify the agriculture sector as one of their priority sectors, and many Member States are applying specific measures to improve the adaptation of the agriculture sector.
- The proposed new common agricultural policy for 2021-2027 has adaptation as a clear objective, which should motivate Member States to increase their investments in adaptation measures.
- EU environmental policies are also influencing the agriculture sector by protecting ecosystems and, at the same time, supporting adaptation efforts.

2.1 Introduction

Climate change in Europe is expected to increase precipitation in some regions, leading to high risks of flooding and storm impacts on crops, and decrease it in others, leading to an increase in droughts (IPCC, 2014b). Increased temperatures might lead to longer growing seasons in northern regions, while further exacerbating water availability and drought events in other regions. Crop yields are therefore expected to increasingly vary from year to year as a result of extreme weather events and other factors, such as pests and diseases, thus increasing the sector's vulnerability to further climate impacts without adaptation (IPCC, 2014b). At the same time, management practices in EU agriculture can lead to negative impacts on soil (through compaction and erosion), water (pollution and extraction), biodiversity (loss of habitat), air quality (through ammonia emissions) and climate (through greenhouse gas (GHG) emissions — see Chapter 3) (EEA, 2015c). A range of policies at international and EU levels aim to address the sector's needs and to minimise its impacts. At the national level, Member States have developed national adaptation strategies or action plans and sectoral plans to not only implement these international and EU policies at the national level but also address national specific circumstances. These policies also offer opportunities to increase the sector's resilience to climate change impacts by supporting adaptation (see Chapter 5).

Adaptation can take place at various levels, ranging from local up to global. Policies at the international and EU levels provide an administrative and financial framework for encouraging adaption at farm level in the EU. Even with an adaptation-friendly policy framework in the EU, adaptation at the farm level does not necessarily take place due to a number of factors, including the policies' non-binding nature, political urgency to adapt, and lack of resources for investment, of institutional capacity, of access to adaptation knowledge and of information (including a lack of coherence between planning tools) (Massey et al., 2014).

At the same time, trade, which is governed by various trade agreements/policies, has a major impact on agricultural production and affects both mitigation and adaptation efforts. Agricultural trade liberalisation can be viewed as an adaptation strategy in the face of

([6]) As of May 2019.

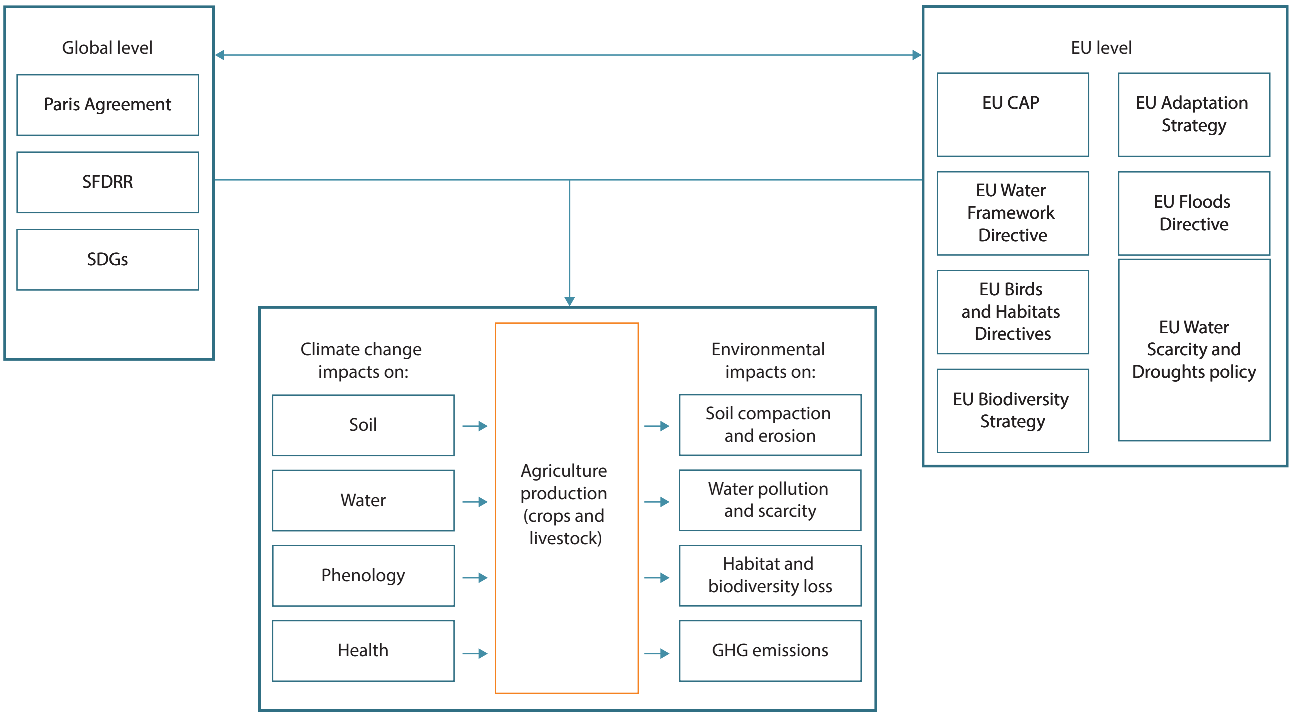
climate change to an extent that remains to be defined (Ouriach et al., 2018). However, trade flows and the dynamics of feedbacks between climate change and trade in the future depend on several factors including policy, markets, individuals' preferences and resilience (Tamiotti et al., 2009).

This chapter looks into the international and EU policy frameworks to analyse whether they hamper or foster adaptation to climate change in the agriculture sector. Agricultural production depends on climate conditions, which have been altered by climate change (see Chapter 4). At the same time, agricultural production can have negative impacts on the environment, leading to soil compaction and erosion, water pollution and scarcity, habitat and biodiversity loss, and GHG emissions (see Chapter 3). There are a number of policies at the global and EU levels aiming to address climate change impacts on agricultural production or to support the need for the sector to adapt to climate change, taking into account environmental impacts (Figure 2.1). Drivers of and barriers to effective adaptation are investigated by reviewing the broad range of assessments that study how the existing EU policy framework contributes to adaptation at farm level (see Chapter 5).

2.2 International climate change policies addressing the agriculture sector

International policies play a key role in highlighting the importance of adapting to climate change in the agriculture sector at a global level. They drive action at a global level and are important drivers for policy action at the EU level. A significant opportunity to address climate change concerns has been generated by simultaneously adopting milestone United Nations agreements. The 21st Conference of the Parties (COP 21) Paris Climate Conference, the Sendai Framework for Disaster Risk Reduction and the Sustainable Development Goals (SDGs) characterise an important and coherent policy framework, which aims to create an adaptive governance system at different administrative levels, with the final aim of increasing resilience and reducing existing risks.

Figure 2.1 Overview of the international and EU policy framework for climate change adaptation in the agriculture sector



Note: The figure presents the global and EU level policies related to agricultural production in the context of climate change impacts on agriculture and agricultural impacts on the environment.
SDGs, Sustainable Development Goals.
SFDRR, Sendai Framework for Disaster Risk Reduction.

Source: EEA.

The Paris Agreement on Climate Change (UNFCCC, 2015) is the first universal, legally binding global deal to combat climate change and adapt to its effects. Having met the ratification threshold, it entered into force on 4 November 2016 and will be operational from 2020 onwards. The aim of the Paris Agreement is to strengthen the global response to the threat of climate change by keeping the global temperature rise this century well below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5 °C (IPCC, 2018). In addition, the agreement aims to strengthen the ability of countries to deal with the impacts of climate change. To reach these ambitious goals, appropriate financial flows, a new technology framework and an enhanced capacity-building framework will be put in place, thus supporting action by developing countries and the most vulnerable countries, in line with their own national objectives. Under the Paris Agreement, intended nationally determined contributions (INDCs) have been agreed in which countries have outlined their priorities and measures. Most Parties to the United Nations Framework Convention on Climate Change (UNFCCC) include agriculture at the centre of their mitigation targets (80 % of the Parties to the UNFCCC) and adaptation strategies (64 % of the Parties to the UNFCCC). At COP 24, a comprehensive set of rules was adopted that defines how climate action is implemented, including how countries should report their GHG emissions or contributions to climate finance.

At COP 17, agriculture was brought into the negotiations for preparing the Paris Agreement by requesting that the technical body (Subsidiary Body for Scientific and Technological Advice, SBSTA) of the UNFCCC consider different topics relating to agriculture and climate change. After years of discussions and negotiations, COP 23 led to a decision on the next steps for agriculture within the UNFCCC framework by establishing the Koronivia Joint Work on Agriculture (UNFCCC, 2017). It aims to develop and implement new strategies for adaptation and mitigation within the agriculture sector that will help reduce emissions from the sector as well as build its resilience to the impacts of climate change. The first Koronivia workshop, 'Modalities for implementation of the outcomes of the five in-session workshops on issues related to agriculture and other future topics that may arise from this work', was held at COP 24. The Joint Work on Agriculture emphasised the need to explore further the potential for synergies among existing processes and to find practical ways to support Parties in the development of advanced agricultural practices to adapt to climate change (Nemitz, 2018).

On 18 March 2015 prior to the Paris Agreement, members of the United Nations adopted the Sendai Framework for Disaster Risk Reduction 2015-2030. It sets targets and four specific priorities for action (UN, 2015a):

- understanding disaster risk;
- strengthening disaster risk governance to manage disaster risk;
- investing in disaster risk reduction for resilience;
- enhancing disaster preparedness to ensure an effective response and to 'build back better' in recovery, rehabilitation and reconstruction.

In addition, a set of 38 indicators was identified to measure global progress in the implementation of the Sendai Framework. The indicators measure progress in achieving the global targets of the Sendai Framework and determine global trends in the reduction of risk and losses. Among those included under Target C (addressing the reduction of direct disaster economic loss in relation to gross domestic product by 2030), sub-indicator C-2 'Direct agriculture losses attributed to disasters' aims to monitor the trends in losses in the agriculture sector. Sub-indicator C-3 monitors direct economic loss of all other damaged or destroyed productive assets attributed to disasters in the agriculture sector ([7]). The indicators include losses in crops, livestock, fisheries, apiculture, aquaculture and forestry and associated fatalities and infrastructure. In 2018, a technical forum was launched with the aim of reviewing progress related to the Sendai Framework monitoring process. It addressed data requirements, analytical capabilities and levels of application (global, regional, national and local). Progress on implementing the Sendai Framework was also started in 2018.

The 2030 agenda for sustainable development (UN, 2015c) embraces 17 SDGs with 169 policy targets and more than 300 indicators. Agriculture is at the core of the 2030 agenda in different forms, including in all 17 goals for sustainable development. Several goals directly address food and agriculture and climate change. The SDGs most relevant to agriculture and climate change are SDG 2 — end hunger, achieve food security and improved nutrition and promote sustainable agriculture; SDG 6 — ensure availability and sustainable management of water and sanitation for all; SDG 12 — ensure sustainable consumption and production patterns; SDG 13 — take urgent action to combat climate change and its impacts; and SDG 15 — sustainably manage forests, combat desertification, halt

([7]) https://www.preventionweb.net/drr-framework/sendai-framework-monitor/indicators and reverse land degradation, halt biodiversity loss. To achieve these goals, adaptation and transformation of the sector is needed.

The goals and targets are the core component of the new and ambitious global framework to achieve sustainable development and eradicate poverty (UN, 2015c). It paves the way for a transition towards greener, fairer and more inclusive development, building upon international collaboration and partnership between states, non-state stakeholders and civil society (UN, 2015c). To make the SDGs related to agriculture more tangible, the Food and Agriculture Organization of the United Nations published a guide for national policymakers that defines a set of actions on how to transform the agriculture sector. The relevant actions for the agriculture sector in relation to climate change include (FAO, 2018c):

- Facilitate access to productive resources, finance and services to enhance agriculture productivity, encourage mechanisation and the use of advanced technology and promote local food systems (SDGs 1, 2). This can also support mitigation of and adaptation to climate change.
- Encourage crop diversification in production (SDGs 1, 2, 15). Crop diversification is an adaptation measure.
- Improve farmers' knowledge and capacity through advice and training (SDGs 1, 2, 13, 15). Improved knowledge can also support mitigation of and adaptation to climate change.
- Enhance soil health and restore land through better management practices (SDGs 1, 2, 12, 15). Healthy soils are essential for mitigation of climate change.
- Protect water and manage scarcity through policies and irrigation efficiency measures (SDGs 1, 2, 6, 12, 15). These are important adaptation measures.
- Mainstream biodiversity conservation and protect ecosystem functions (SDGs 1, 2, 6, 12, 15). This can also support mitigation of and adaptation to climate change.
- Prevent, protect and respond to shocks through disaster risk reduction, early warning systems (SDGs 1, 2, 13). These are important adaptation measures.

On the one hand, because of the complexity of the interrelation between these international climate change policies, which all address adaptation in the agriculture sector, there is a risk that activities under these policies remain fragmented without taking advantage of the overlaps. On the other hand, the different policies can complement each other: the draft Decision of the Adaptation Committee from the COP 24 ([8]) event encourages parties to strengthen adaptation planning by taking into account linkages with the monitoring systems of the SDGs and the Sendai Framework.

2.3 Adaptation and agriculture policies at EU level and links to national policies

The EU strategy on adaptation to climate change (the adaptation strategy) aims to enhance resilience to and preparedness for current and future climate impacts by better integrating adaptation actions into key sectors of the EU. The common agricultural policy (CAP) serves as the main policy framework for the agriculture sector. Together, the adaptation strategy and the CAP offer various opportunities for EU Member States to adapt the agriculture sector to climate change. Environmental policies in the field of water management (including floods) and biodiversity further complement the CAP and the EU adaptation strategy in encouraging adaptation actions within the agriculture sector.

2.3.1 The EU strategy on adaptation to climate change

The EU strategy on adaptation to climate change (EC, 2013b), adopted in 2013, includes three key objectives and eight sub-actions. The three key objectives are described below.

Promoting action by Member States: the Commission encourages all Member States to adopt comprehensive adaptation strategies and provides funding to help them build up their adaptation capacities and take action.

As of 2019, 28 European countries (25 EU Member States and three EEA member countries) have adopted their national adaptation strategy and 17 (15 EU Member States and two EEA member countries) have developed their adaptation plan. Based on results of the 2019 reporting under the Monitoring Mechanism Regulation (MMR), all national adaptation strategies explicitly addressed the agriculture sector as one of the priority sectors. Twenty EU Member States prepared specific climate change impacts and vulnerability assessments and 13 Member States introduced

([8]) https://unfccc.int/sites/default/files/resource/cp24_auv_adap%20cttee.pdf

Table 2.1 Overview of the EU Member States' national adaptation strategies, impacts assessment and adaptation measures addressing explicitly the agriculture sector

Country	Agriculture addressed in NAS/NAP as a priority sector	Specific CCIV assessment for agriculture prepared	Specific adaptation measures for agriculture defined
Austria	[blue]	[blue]	[blue]
Belgium	[blue]	[blue]	[blue]
Bulgaria	NAS/NAP not available	[blue]	[blue]
Cyprus	[blue]	Information not provided	Information not provided
Czechia	[blue]	[blue]	[blue]
Germany	[blue]	[blue]	[orange]
Denmark	[blue]	[blue]	[orange]
Estonia	[blue]	[orange]	[orange]
Greece	[blue]	[orange]	[orange]
Spain	[blue]	[blue]	[blue]
Finland	[blue]	[blue]	[blue]
France	[blue]	[blue]	[orange]
Croatia	NAS/NAP not available	[blue]	[orange]
Hungary	[blue]	[orange]	[orange]
Ireland	[blue]	[orange]	[orange]
Italy	[blue]	[blue]	[orange]
Lithuania	[blue]	[blue]	[blue]
Luxemburg	[blue]	[blue]	[blue]
Latvia	NAS/NAP not available	[blue]	[orange]
Malta	[blue]	[blue]	[blue]
Netherlands	[blue]	[blue]	[orange]
Poland	Information not provided	Information not provided	Information not provided
Portugal	[blue]	[blue]	[blue]
Romania	[blue]	[blue]	[blue]
Sweden	[blue]	[orange]	[orange]
Slovenia	[blue]	[blue]	[blue]
Slovakia	[blue]	[blue]	[blue]
United Kingdom	[blue]	[orange]	[orange]

Note: The table is based solely on the reporting by the EU Member States under GHG MMR Article 15 — national adaptation actions in 2019. Blue denotes agriculture being addressed, orange denotes agriculture not being explicitly addressed and red denotes information not available in the reports.

Source: Climate-ADAPT

specific adaptation measures at national and regional levels (Table 2.1). In addition, various Member States (e.g. Malta, Romania) also mainstreamed climate change adaptation into national agricultural policies, and several Member States (e.g. Slovenia) developed specific adaptation strategies for the agriculture sector.

Better informed decision-making by addressing gaps in knowledge about adaptation and further developing the European Climate Adaptation Platform (Climate-ADAPT) to provide information on adaptation information in Europe.

One of the objectives of Climate-ADAPT is to facilitate the collection, sharing and use of information on climate change impacts, vulnerability and adaptation, and build a consistent and up-to-date knowledge base (EEA, 2018e). The platform collects and presents case studies on adaptation in different sectors (for the agriculture sector, as of 2019, seven case studies are available). It assists the effective uptake of relevant knowledge by decision-makers and contributes to a greater level of coordination among sectors and institutional levels. Climate-ADAPT also includes the links to data and information on climate change from providers such as the Copernicus Climate Change Service (C3S) [9] to enhance knowledge on adaptation.

Climate-proofing action at EU level by further promoting adaptation in key vulnerable sectors such as agriculture, fisheries and the cohesion policy, ensuring that Europe's infrastructure is made more resilient, and promoting the use of insurance against natural and disasters resulting from human activity.

Action 6 (under objective 3 of the EU strategy on adaptation to climate change) links climate change to the agriculture sector, with a focus on climate-proofing of the CAP. To support that process, various Commission staff working documents (SWDs) and green papers have been developed that focus on different aspects of adapting agriculture to climate change. The most relevant is the SWD *Principles and recommendations for integrating climate change adaptation considerations under the 2014-2020 rural development programmes* (EC, 2013a). This document was intended to ensure that climate adaptation objectives are embedded in the design of their 2014-2020 rural development programmes (RDPs). It aimed to address the managing authorities and all stakeholders involved in RDP preparation and consultation, including climate experts and external stakeholders.

In 2018, the European Commission published an evaluation of the EU adaptation strategy (EC, 2018h). The evaluation showed that the strategy has delivered on its objectives, with progress recorded against each of its eight individual actions. However, the progress is different in the various sectors. Nevertheless, the report outlines how Europe is still vulnerable to climate impacts within and outside its borders. Among the four sectors assessed in the evaluation, the cross-border effects are the strongest in the agriculture sector (EC, 2018c).

2.3.2 The EU common agricultural policy

The EU CAP is the main policy that influences the development of the agriculture sector in the EU. The CAP has evolved over time, and today there is a greater focus on the environment and climate, among other objectives. The CAP is a strong economic driver of farming decisions across the EU and influences how individual farmers choose to manage their land, crops and livestock and how they use inputs, including energy, fertilisers and water, which is still leading to negative effects on the environment in some regions (Gocht et al., 2017).

The current CAP governing the period 2014-2020 and the 2018 proposal for the CAP post-2020 (period 2021-2027) have integrated adaptation to climate change into the policy framework. The regulations on direct payments and rural development not only offer opportunities but also continue to create potential disincentives for farmers to enhance the resilience of their farms and reduce their vulnerability to climate change impacts (EC, 2019).

The 2014-2020 CAP consists of three main elements [10]:

1. direct payments to farmers, including a requirement to comply with sustainable agricultural practices, accounting for 72 % of the CAP budget (EUR 41.74 billion annually);

2. market support measures, accounting for around 5 % of the CAP budget (EUR 2.7 billion annually); and

3. rural development measures, accounting for almost 25 % of the CAP budget (EUR 14.37 billion annually).

The CAP accounts for around 38 % of the overall EU budget in the period 2014-2020. The current version of the CAP aims to:

- support farmers and improve agricultural productivity so that consumers have a stable supply of affordable food;
- ensure that EU farmers can make a reasonable living;
- help tackle climate change and the sustainable management of natural resources;
- maintain rural areas and landscapes across the EU;
- keep the rural economy alive promoting jobs in farming, agri-foods industries and associated sectors.

Pillar 1: direct payments

About 95 % of the **Pillar 1** budget is used for direct payments and the remainder for activities that support agricultural markets, such as support for cotton production (EC, 2018g). Direct payments are tied to environmental requirements through the following

(9) https://climate.copernicus.eu
(10) https://ec.europa.eu/info/food-farming-fisheries/key-policies/common-agricultural-policy/cap-glance_en

- cross-compliance (adhering to statutory mandatory requirements (SMRs) of EU environmental legislation and good agriculture and environmental conditions (GAECs); and
- green direct payments (greening), which account for 30 % of EU Member States' annual ceilings for direct payments; these take the form of an annual payment per eligible hectare and are conditional upon farmers respecting three generalised, non-contractual annual actions.

In 2015, cross-compliance applied to 7.5 million farmers who received approximately EUR 47 billion in aid (11).

SMRs cover 13 legislative standards in the fields of environment, food safety, animal and plant health and animal welfare. SMRs are not directly linked to climate change adaptation. However, they reinforce the basis for environmental standards that the agriculture sector has to comply with by linking the direct payments via cross-compliance to this basis. However, the provisions under the Nitrates Directive (Directive 91/676/EEC) — which aims to protect water quality across Europe by preventing nitrate from agricultural sources from polluting ground and surface waters and by promoting the use of good farming practices — is indirectly linked to climate change mitigation in that measures under the Nitrates Directive control activities related to livestock and fertiliser management that release nitrous oxide (N_2O) and methane (CH_4). Under the GAECs, there is no objective specifically linked to climate change, but requirements on farming management practices are indirectly linked to increased carbon sequestration and maintain soil carbon stock. In many regions, clean water is also becoming more essential, with increased water scarcity resulting from climate change.

Greening measures include crop diversification, permanent grassland and ecological focus areas. These measures are partially linked to climate change, mainly in mitigation measures, and have less direct relevance to adaptation. While crop diversification and certain types of ecological focus areas (12) (e.g. catch and cover crops) can be linked to adaptation benefits (see Section 5.3.3 for details), their contribution is nominal. In the literature, these measures can increase a farm's resilience and decrease a farmer's vulnerability to weather and climate extreme events (Sutton et al., 2008; Sanderson et al., 2013; Isbell et al., 2017; Roesch-McNally et al., 2018), as well as reduce the risk of soil degradation (Blanco-Canqui et al., 2015; Delgado et al., 2011; Posthumus et al., 2015).

With respect to adaptation to climate change, Pillar 1 supports financing that can lead to maladaptation within the agriculture sector. Pillar 1 provides, besides other things (13), some crop-specific payments for cotton, limited to a certain base area per Member State, which should be reconsidered in the context of adaptation to avoid maladaptation. The purpose of the crop-specific payments is to avoid production being abandoned in regions where the crop is important for the agricultural economy (14). Given this, certain production types may continue, although they are not economically or environmentally viable. In the context of adapting to climate change, with increasing water scarcity and droughts and extreme temperatures, Member States should, in the long run, consider supporting farmers to switch production types to those more conducive to the environment and more resilient to climate change. For example, cotton is known for its water intensity. In 2013, EU cotton production was estimated at less than 300 000 t, which amounts to only 1 % of world cotton production. With 230 000 t, Greece accounts for 85 % of EU production, whereas Spain produces the remaining 15 % (40 000 t) (15). In both countries, cotton is grown almost entirely on irrigated land using drip irrigation techniques (16).

Pillar 2: Rural development

Pillar 2 of the CAP addresses rural development through the European Agriculture Fund for Rural Development (EAFRD). The EAFRD requires Member States to draw up RDPs, which set priorities and objectives for the development of rural areas. The RDPs are the main financing programme for the implementation of specific environmental and climate measures at farm level (see Chapter 5).

The EAFRD identified six priorities and focus areas for the 2014-2020 programming period. Particularly relevant for climate change adaptation are priority 4 — Restoring, preserving and enhancing ecosystems — and priority 5 — Promoting resource efficiency and transition to a low-carbon economy. Within priority 5, two focus areas are directly relevant to

(11) These 7.5 million farmers represent 68 % of all farmers supported by the CAP and receive 83 % of all payments. Small farmers are not included in these figures, as they are not subject to administrative penalties if they do not comply with cross-compliance obligations (ECA, 2016).
(12) The choice of measure is up to the Member State, with variations found across the EU.
(13) Under Regulation 2017/2393Article 52, Member States may grant, under certain conditions, coupled support to farmers in specific agricultural sectors or types of farming, to the extent necessary to create an incentive to maintain current levels of production in the sectors or regions concerned.
(14) https://ec.europa.eu/agriculture/cotton_en
(15) https://ec.europa.eu/agriculture/cotton_en
(16) http://www.fao.org/docrep/007/j2732e/j2732e05.htm

climate change: priority 5d on reducing GHG and ammonia emissions and priority 5e on fostering carbon conservation and sequestration. Under these priorities, the Member States can develop thematic sub-programmes — climate change adaptation is explicitly mentioned — and offer concrete measures for financing (Kantor, 2015). In addition, the Leader programme (an acronym in French — *Liaison entre actions de développement de l'économie rurale* — meaning links between actions for the development of the rural economy), focusing on bottom-up, community-developed local strategies, can be used to develop joint initiative and pilot-type projects including, among other things, for adaptation. A minimum of 5 % of RDP funding must go to such initiatives. Local action groups can identify key issues, such as adaptation, and develop a local development strategy. During the previous RDP financial periods, the Leader programme has been used for climate-focused projects such as adaptation and resilience-building through land management planning; creating flood risk management plans; increasing coordination between local stakeholders for sustainable management and to reduce landscape fragmentation; encouraging planting of traditional cultivars; restoring peatlands/wetlands; native tree planting; and enhancing depleted agricultural soils to increase the humus content and carbon sequestration potential (Frelih-Larsen et al., 2014).

Under the Omnibus Regulation (EU, 2017), climate change has been considered further, and support for insurance contracts, which cover, among other things, losses caused by adverse climatic events, become available when more than 20 % of the farmer's average annual production is destroyed.

Assessments of the inclusion of adaptation into the EAFRD focus on two main aspects: (1) climate mainstreaming; and (2) tracking climate-related expenditure. Climate mainstreaming is supported under the EAFRD by the requirement for RDPs to spend at least 30 % on a range of climate and environmental measures (EC, 2017a). This requirement provides minimally useful information, as climate and environment are addressed together and not separate. This minimum requirement includes measures that do not appear to have a significant impact on the achievement of climate objectives (EC, 2017a, 2018c). Tracking methodology of climate-related expenditure does not offer specific adaptation information, as funding is tracked at priority level, which includes multiple focus areas beyond climate mitigation and adaptation. Therefore, in the tracking of financing, measures such as natural resources conservation/management not directly targeted at adaptation with adaptation co-benefits have been included (EC, 2018c).

The European Court of Auditors (ECA) concluded that a more conservation tracking methodology would reduce the overall climate allocations under the EAFRD by 42 % (ECA, 2016). Moreover, the methodology does not differentiate between allocations for climate mitigation and adaptation, so it is not possible to determine how much is spent on adaptation efforts (EC, 2018c). Therefore, the lack of an adaptation-specific priority or focus area creates difficulty in both clearly identifying and tracking adaptation action (EC, 2018c).

Despite the objective-setting framework, the ability of Member States to have adaptation measures co-financed under rural development and the minimum budget requirements, the EAFRD has gaps in addressing water management and enables maladaptation through investments in irrigation. To address the issue that investments in irrigation do not necessarily reduce water consumption (either due to farmers switching to more water-intensive crops or due to the expansion of its irrigation network), the 2013 Rural Development Regulation (Regulation EU/1305/2013) includes Article 46, which defines criteria for ensuring minimum water savings for irrigation investments and linking investments to requirements under the EU Water Framework Directive (WFD). Nevertheless, the EAFRD has a major gap in its implementation, as Article 46 is applicable only to irrigation investments programmed under the focus area to improve water use efficiency and does not apply to irrigation investments programmed under the focus area to improve the economic performance of farm. The 2018 CAP proposal eliminates Article 46. In its place is the requirement that certain programmes under the CAP strategic plans can finance irrigation but not near water bodies in poor status, as defined under the WFD. In the current CAP proposal, the language is vague, and it is unclear how the requirements will be implemented. Moreover, the same gaps in implementation remain, as in the previous period, as irrigation can be financed under other programmes under the strategic plans that do not have any limitations on investments.

2.3.3 Integration of adaptation in the common agricultural policy

The current CAP (2014-2020) itself has mainstreamed adaptation into its policy framework. The evaluation of the EU adaptation strategy (published in December 2018) concluded that, without the strategy, an equivalent amount of progress would not have been made in climate-proofing key EU policies such as agriculture (EC, 2018c). Nevertheless, the CAP continues to include provisions that counteract adaptation efforts. Moreover, multiple evaluations of the CAP have shown that Member States' efforts to include adaptation in their RDPs have been limited.

Efforts under Pillar 1 to 'green' direct payments were not successful. An evaluation after 2 years of implementation on the greening of the CAP showed that Member States tend not be very ambitious of their own accord, especially with respect to ecological focus areas and crop diversification (Alliance Environnement and the Thünen Institute, 2017). Similar findings are reported by the ECA (2017), in which it is stated that Member States use the flexibility in greening rules to limit the burden on farmers and themselves, rather than to maximise the expected environmental and climate benefit. Also, the OECD (2017) reported that the impact of greening on GHG emission reductions seems to be minor.

Assessments of the implementation of the CAP in the Member States have shown that, while the policy framework offers a number of opportunities to include adaptation measures, the Member States have not shown significant ambition to do so. The following statistics, as regards the inclusion of climate change investments, are based on the data submitted by Member States to the Commission by the end of 2015 (Dumitru, 2018):

- 7.6 % of agricultural land under management contracts targeting reduction of GHG and/or ammonia emissions;
- livestock management changes for 2 % of livestock units with a view to reducing GHG and/or ammonia emissions;
- 15 % of irrigated land switching to more efficient irrigation systems;
- EUR 2.8 billion total investment in energy efficiency;
- EUR 2.7 billion invested in renewable energy production;
- 4 % of agricultural and forestry land under management to foster carbon sequestration/ conservation.

Furthermore, the assessment of integrating adaptation into the European Structural and Investment Funds 2014-2020 shows the following (COWI, 2017):

- 77 % of the total EAFRD support for climate action can be assumed to deliver adaptation and/or mitigation benefits, while 13 % delivers dedicated adaptation benefits. However, this situation results from broad allocation to priority 4, 'Restoring, preserving and enhancing ecosystems', and the fact that several of the relevant measures have multiple effects on the environment. This has made it difficult for managing authorities to distinguish between adaptation, mitigation and more traditional environmental management related to conservation and protection of resources, habitats, biodiversity, etc.
- Under priority 3b, 'Supporting farm risk prevention and management', in combination with measures M5 and M17, funding is allocated to address a number of the key climate hazards, such as drought, forests fires, pest, invasive species, mudslides, flooding and heavy rainfall. This — and the regional differences in use of the measures — indicates great attention being paid to the need to address relevant climate hazards, in particular in southern and central Europe.

As of 2017, Member States have not taken much advantage of the Leader programme to address adaptation. The focus has mostly been on climate change mitigation.

The 2018 evaluation of the EU adaptation strategy shows that, while adaptation has been well acknowledged in almost all of the RDPs, it is seldom the objective determining the choice of the specific measures. This is especially so because of the difficulty of separating mitigation- and adaptation-related measures in agriculture and forestry sectors. Moreover, the adaptation measures offered focus much more on actions that directly benefit farm businesses (e.g. support for more efficient irrigation systems) than on delivering wider public benefits (e.g. land management practices that reduce flood risks) (EC, 2018c). In addition, the contribution of the RDPs to adaptation has been overestimated, largely as a result of the tracking methodology, which includes measures on natural resource conservation/management not directly targeted at adaptation but with adaptation co-benefits (EC, 2018c).

According to the results of the Economics of Climate Change Adaptation (EconAdapt) project [17], the current CAP system still bears the risk that, despite the large amount of CAP subsidies, or even as a result of these CAP subsidies, the agriculture sector is still developing in a direction that makes it even more vulnerable to weather extremes that may occur under climate change (Zhu et al., 2016). For instance,

([17]) https://econadapt.eu

droughts in the Mediterranean regions may have severe impacts on the agriculture sector, and the investments in the agriculture sector (e.g. irrigation) that are currently taking place may lead to more risks in the future, because of a lack of water availability in other sectors. Similarly, the extension of the dairy and livestock sector, which is at least to some extent enabled by agricultural support under the CAP, has the potential to lead to higher emissions of GHGs and larger environmental impacts. These sectors can also be more vulnerable to new diseases appearing under climate change.

2.3.4 The proposed common agricultural policy 2021-2027

On 1 June 2018, the Commission presented a single legal proposal for the future CAP ([18]). The CAP proposal calls for the Member States to develop a singular CAP strategic plan that covers both direct payments (Pillar 1) and rural development payments (Pillar 2). Under the CAP proposal, there are now four entry points for implementing technical measures at farm level to promote adaptation to climate change: enhanced conditionality, the eco-schemes, the sectoral interventions and the rural development interventions ([19]). Eco-schemes are a new intervention under Pillar 1, requiring Member States to offer financing for agri-environment-climate measures; these are in addition to the same type of measures required under the rural development interventions (formerly RDPs). Sectoral interventions are specific programmes linked to production types (e.g. fruit and vegetables, vineyards, hops).

Table 2.2 briefly shows selected cases how adaptation has been further integrated into the policy framework for the future cycle (2021-2027) compared with the current programming period (2014-2020).

Table 2.2 Examples of integration of adaptation into the current and proposed CAP framework

	Current programming cycle (2014-2020)	Future cycle (2021-2027) — under the proposed CAP Strategic Plans Regulation
Objectives	Indirect support for adaptation in cross-compliance regime and greening provision.	Greening provision has been eliminated. Crop rotation requirements have been added to enhanced conditionality (i.e. cross-compliance). Crop rotation has adaptation benefits, such as reducing the spread of pathogens.
	Pillar 1 only includes direct payments and coupled payments such as those for cotton. No references to climate change adaptation for Pillar 1 payments.	Under Pillar 1, the newly introduced eco-schemes (agri-environment-climate measures) are required to be implemented, although which measures to offer is up to Member States. Adaptation to climate change and sustainable use of water resources are included as objectives. The newly introduced sectoral interventions include adaptation as an objective and enable Member States to finance technical and capacity-building measures to adapt to climate change.
	The main objectives of the RDPs (Pillar 2) is to create a coherent and sustainable framework that safeguards the future of rural areas, building on, in particular, its ability to provide a range of public services that transcend the simple production of food and the ability of rural economies to create new sources of food income and employment by protecting the culture, environment and heritage of rural areas. Adaptation is a cross-cutting objective, with no defined objective upon which measures have to be designed to achieve it.	Adaptation is now a specific objective that Member States can focus their financing on. In total, 30 % of the national budget for rural development must be invested in the 'greening' processes (agri-environment-climate measures, investments related to the environment and climate, forestry measures, organic farming and Natura 2000).

([18]) 'Proposal for a Regulation of the European Parliament and of the Council establishing rules on support for strategic plans to be drawn up by Member States under the Common agricultural policy (CAP Strategic Plans) and financed by the European Agricultural Guarantee Fund (EAGF) and by the European Agricultural Fund for Rural Development (EAFRD) and repealing Regulation (EU) No 1305/2013 of the European Parliament and of the Council and Regulation (EU) No 1307/2013 of the European Parliament and of the Council.'

([19]) Member States can choose which measures to offer under eco-schemes. The main difference between the eco-schemes and the agri-environment-climate measures is that eco-scheme operations need to be implemented for a minimum of only 1 year and can also cover costs beyond income foregone and costs incurred.

Table 2.2 Examples of integration of adaptation into the current and proposed CAP framework (cont.)

	Current programming cycle (2014-2020)	Future cycle (2021-2027) — under the proposed CAP Strategic Plans Regulation
Farm advisory systems	The farm advisory system (FAS) is obligatory under the CAP and aims to help farmers better understand and meet the EU rules for environment, public and animal health, animal welfare and the GAEC. At a minimum, the FAS needs to be linked to at least one priority (which could be adaptation) and has to cover one issue from a list of issues, including cross-compliance and agricultural practices beneficial for the climate and the environment. Consequently, this helps farmers to implement appropriate solutions for their specific situations, including aspects of climate change adaptation, even if it is not mandatory. Whether to include adaptation advice is up to the Member States.	The FAS remains a part of the CAP. Shifting from the current regulation, the FAS must not cover all aspects listed in the proposal, which include advice on all requirements, conditions and management commitments under conditionality and any operations established under the CAP strategic plans. Consequently, any plan that includes adaptation measures must also offer adaptation advice to farmers. The proposal makes references to up-to-date technological and scientific information developed by research and innovation and is linked to the Agricultural Knowledge and Innovation System.
Measures	RDPs must include agri-environment-climate measures that can be used to adapt to climate change. In addition to those measures, investments in the restoration of agricultural or forestry potential following natural disasters or catastrophic events and investments in appropriate preventive actions in forests and in the rural environment are also included.	
	The Regulation includes specific requirements for irrigation investments under the RDPs to lead to a minimum 5 % water savings (Article 46), among other things. The lack of application for all irrigation investments represents a serious gap in implementation. Some RDPs chose to only offer irrigation grants under focus area 2b to circumvent the minimum water-saving requirements.	Article 68, 3 (f) includes specifics on ineligible investments and replaces Article 46. It stipulates that investments in irrigation that are not consistent with achieving good status of water bodies, as laid down in the WFD, including expansion of irrigation affecting water bodies whose status has been defined as less than good in the relevant river basin management plan, cannot be financed. This provision is not fully clear for the following reasons: A reference is made to status in general —it is not clear whether this provision would also apply to water bodies failing ecological or chemical status or just those linked to less than good quantitative status. It is also not fully clear how the Commission intends to operationalise the provision 'not consistent with achievement of good status' — whether this would completely prohibit investments in water bodies in less than good status, whether this would consider exemptions under Article 4 of the WFD or not, or whether investments would be allowed that showed water savings. It is very positive that this Article forbids the expansion of irrigation near water bodies failing good status. This is a more stringent provision than that in Article 46, which allowed investments as long as 50 % effective savings could be achieved. However, there is no reference to minimum water savings. Furthermore, the provision requiring metering has been eliminated. The prohibition of investments near water bodies in poor status is only required for irrigation investments under rural development interventions and not under sectoral interventions, which is a serious gap in implementation and could probably lead to irrigation investments being predominately financed under the articles in which such a requirement is not in place.
	Under cooperation measures, those promoting innovation and research into adaptation, for example under the agricultural European Innovation Partnership (EIP-AGRI) focus groups, can be financed, as well as joint actions on adaptation.	
	RDPs can offer a measure on risk management tools.	Offering risk management tools to farmers is now mandatory. This also includes insurance schemes, which are an adaptation measure to climate change.
	Under the RDPs, Member States can set up Leader groups, an initiative to support projects at the local level to revitalise rural areas and create jobs. Member States must spend at least 5 % of the RDP budget on Leader activities. Projects can include adaptation activities.	

2.4 Other EU environmental policies

The CAP and its financing mechanisms and the EU strategy on adaptation to climate change represent two main policy groups in the agriculture sector that encourage the implementation of adaptation measures in Member States. However, there are also EU environmental policies in place that address the impacts of the agriculture sector on the environment. At the same time, the environmental policies also stimulate adaptation action and contribute to disaster risk reduction within the agriculture sector. The main group of environmental policies consists of the EU biodiversity strategy, the WFD, and the Floods Directive, among other policies.

2.4.1 Biodiversity

Healthy ecosystems lie at the centre of any adaptation policy and can help mitigate climate change impacts by absorbing excess flood water or acting as a buffer against coastal erosion or extreme weather events. This was recognised by the EU strategy on adaptation to climate change. The EU biodiversity strategy for 2020 aims to integrate biodiversity needs into the development and implementation of sectoral policies. The three targets relevant to climate change adaptation are (1) the full implementation of the EU nature legislation; (2) better protection and restoration of ecosystems and the services they provide, and greater use of green infrastructure; and (3) more sustainable agriculture and forestry. Agriculture is very often a main driver of biodiversity loss, so it is important to remember that farmers can play a key role in maintaining and managing Europe's biodiversity and therefore contribute to adaptation (EEA, 2015c). Recognising this, the European Commission published a guidance document in 2013 on dealing with climate change impacts in Natura 2000 areas (EC, 2013c).

2.4.2 Water

The WFD, adopted in 2000, sets the objectives for water protection in the EU. It defines the objectives for sustainable water and management of water bodies, which is essential to maintain good conditions of ecosystems, human well-being, health and prosperity. The water directors of EU Member States adopted, in December 2009, a guidance document on adaptation to climate change in water management (EC, 2009) to ensure that the river basin management plans (RBMPs) are climate-proofed. As the measures in the RBMPs also address agricultural practice, the RBMPs will also trigger adaptation towards climate change in the agriculture sector.

The Floods Directive (Directive 2007/60/EC) requires Member States to assess whether all water courses and coastlines are at risk from flooding, to map the extent of flooding and the assets and people at risk in these areas, and to take adequate and coordinated measures to reduce this flood risk. The Communication *Addressing the challenge of water scarcity and droughts* (EC, 2007) proposed actions to prevent and mitigate water scarcity and drought situations, with the priority of moving towards a water-efficient and water-saving economy. Floods, droughts and water scarcity affect the agriculture sector and in turn influence agricultural production in terms of quality and quantity.

The agriculture sector influences the quantity and quality of water bodies in Europe. Despite improvements in some regions, pollution from agriculture remains a major cause of the poor water quality. Fertilisers, pesticides and their metabolites, pollution by livestock and organic pollution from manure, are regularly detected in water bodies at levels sufficient to impact aquatic ecosystems (e.g. through eutrophication) and require treatment where water is abstracted for drinking. However, many of these problems can be alleviated by employing a range of cost-effective on-farm measures to use inorganic and organic fertilisers and pesticides more efficiently. The final result is better water quality.

3 Greenhouse gas and air pollutant emissions from the agriculture sector

Key messages

- Agriculture accounts for around 10 % of all greenhouse gas emissions in the EU. Methane (CH_4) emissions from enteric fermentation make up the largest share (38 %). The sector has a large potential to reduce the non-CO_2 greenhouse gas emission levels and can also significantly contribute to the removal of CO_2 from the atmosphere by converting land cover types and management of soils.
- Between 1990 and 2016, greenhouse gas emissions from agriculture decreased by around 20 % in the EU, and emissions are projected to remain stable after 2020. The agriculture sector will need to decrease emissions to contribute to reaching the EU emission reduction targets by 2030 and 2050.
- Ammonia (NH_3) and primary particulate matter (PM_{10}) are the two most important air pollutants from agriculture. Between 1990 and 2016, emissions of ammonia fell by 18 %, mainly as a result of reductions in livestock numbers and nitrogen fertiliser use.
- To reduce greenhouse gas and ammonia emissions, the sector will need to reduce emissions from fertilisers, manure storage and livestock. This can be achieved through improvements in fertiliser use, in manure handling efficiencies and in animal productivity through breeding, for example.
- Reducing emissions through new farm practices alone will not be sufficient. Changing diets and reducing food losses would contribute to additional reductions.

3.1 Introduction

Agriculture is affected by climate change, but it is also a driver of climate change itself, through the release of greenhouse gases (GHGs). To deal with climate change, Europe needs to adapt its agricultural food system and reduce its emissions from agriculture. Adaptation measures introduced in the European agriculture sector should have clear benefits for climate change mitigation.

Agriculture has a potential to reduce emission levels. Emissions from the sector can be reduced through mitigation practices but also through sequestration of carbon emissions through sustainable production practices. To better understand synergies between mitigation and adaptation in agricultural production systems, this chapter provides an overview of emissions from the sector and trends in such emissions for this sector.

Agriculture (crop and livestock activities) emits CO_2 and non-CO_2 GHGs. The main non-CO_2 GHGs released during agricultural activities are nitrous oxide (N_2O) and methane (CH_4). Emissions in agriculture arise mainly from enteric fermentation (livestock produce CH_4 during digestion), management of agricultural soils, manure left on pasture and manure management. The GHG contribution varies by country, but, in absolute terms, just under 44 % of the total agricultural emissions of the 28 EU Member States is released from France, Germany and the United Kingdom.

Reducing agriculture's carbon footprint [20] is central to limiting climate change. GHG emissions from the sector declined between 1990 and 2016, mainly due to:

- a reduction in livestock numbers (mainly cattle);
- improvements in management practices (decreased use of fertilisers and manure);
- development and implementation of agricultural and environmental policies (e.g. the Nitrates Directive and common agricultural policy (CAP)).

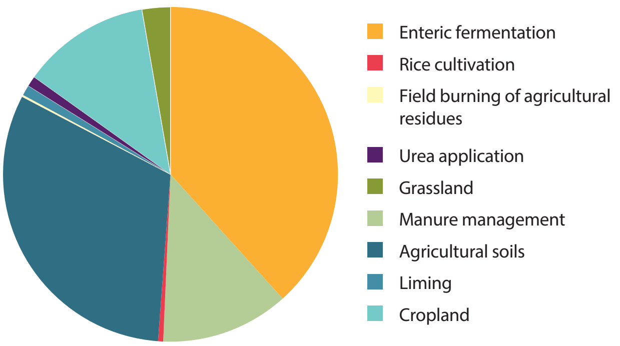
(20) Carbon footprint refers to the total amount of GHGs produced, usually expressed in tonnes equivalent of CO_2.

3.2 Trends in greenhouse gas emissions from agriculture

The agriculture sector is the largest contributor of non-CO_2 GHG emissions. In the EEA member countries ([21]) as a whole, CH_4 emissions from enteric fermentation make up the largest share of all agricultural emissions (38 %), with emissions of N_2O from agricultural soils being the second most significant contributor at 32 % (EEA, 2018g) (Figure 3.1).

Between 1990 and 2016, there was around 20 % decrease in GHG emissions from the agriculture sector (EEA, 2018g) (Figure 3.2). The rate of decline was fastest in the period up until 2000, as a result of a decline in cattle numbers in most countries and a fall in the use of organic and mineral fertilisers. The trends in cattle numbers have been linked to the reorganisation of agricultural practices in eastern Europe and to reforms of the CAP, such as milk quotas and single farm payments, which discouraged over-production. Both of these elements together encouraged more cost-effective agriculture with higher yields per animal but fewer animals (EEA, 2018g). The use of mineral and organic nitrogen fertiliser decreased, because of changes in farming practices and more optimised use of fertilisers (e.g. Borugă et al., 2016). This fall can be partly attributed to the EU Nitrates Directive (91/676/EEC) (EU, 1991), which aimed to protect waters against nitrate pollution by promoting best

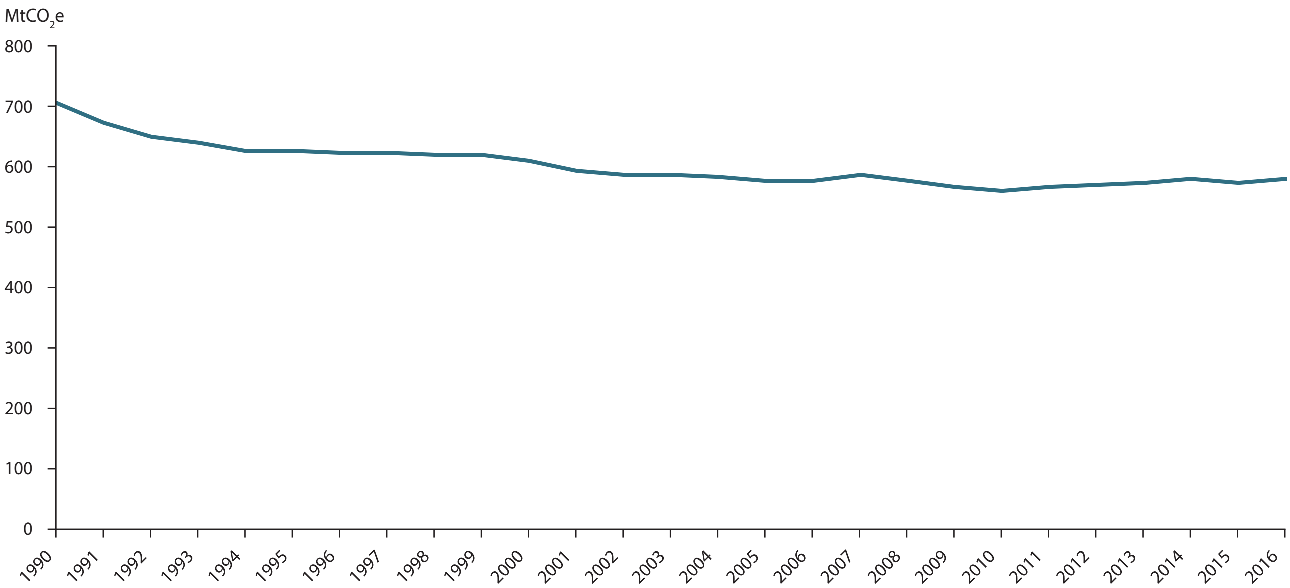
Figure 3.1 GHG emissions from agriculture and agriculture-related land use, land-use change and forestry (LULUCF) in the EEA-33 in 2016, by source category



Notes: Categories presented in the common reporting format, as defined by the Intergovernmental Panel on Climate Change (IPCC) (see EEA, 2018g): These include emissions from the agriculture sector and emissions from cropland (land remaining cropland and land converted to cropland) and grassland (land remaining grassland and land converted to grassland) under the LULUCF sector.

Source: Based on EEA (2018b).

Figure 3.2 Total GHG emissions from the agriculture sector (1990-2016) for the EEA-33



Notes Total GHG emission include emissions from the agriculture sector and emissions from cropland (land remaining cropland and land converted to cropland) and grassland (land remaining grassland and land converted to grassland) under the LULUCF sector.

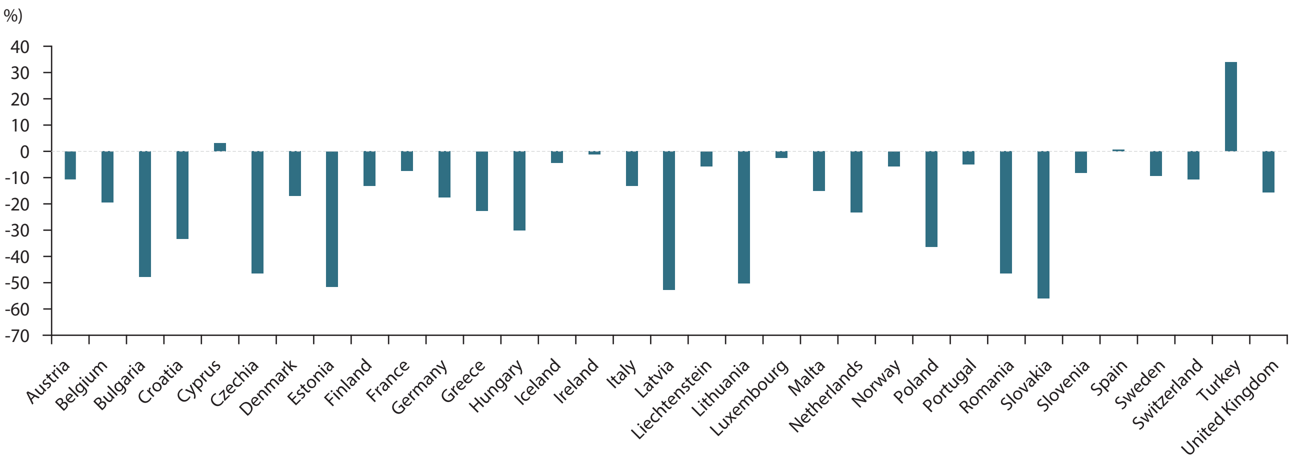
Source: Based on EEA (2018b).

([21]) The 28 EU Member States plus Iceland, Lichtenstein, Norway, Switzerland and Turkey.
([22]) More information is available online (https://ec.europa.eu/clima/policies/forests/lulucf_en)

practice in applying fertiliser and manure to soils (EEA, 2011, 2018g).

There are considerable differences between countries in the agricultural emissions observed between 1990 and 2016 (Figure 3.3). As described above, many countries in eastern Europe have seen large reductions in emissions, mainly due to a large reduction in cattle numbers during the restructuring and modernisation of agriculture (EEA, 2018g). However, Swedish agriculture has also undergone restructuring, resulting in fewer, larger farms with a reduction in the area of cultivated arable land (EEA, 2018g). In contrast, there have been smaller reductions or even small increases in western Europe, for example due to an increase in livestock numbers in Spain and Cyprus in the period 1990-2016

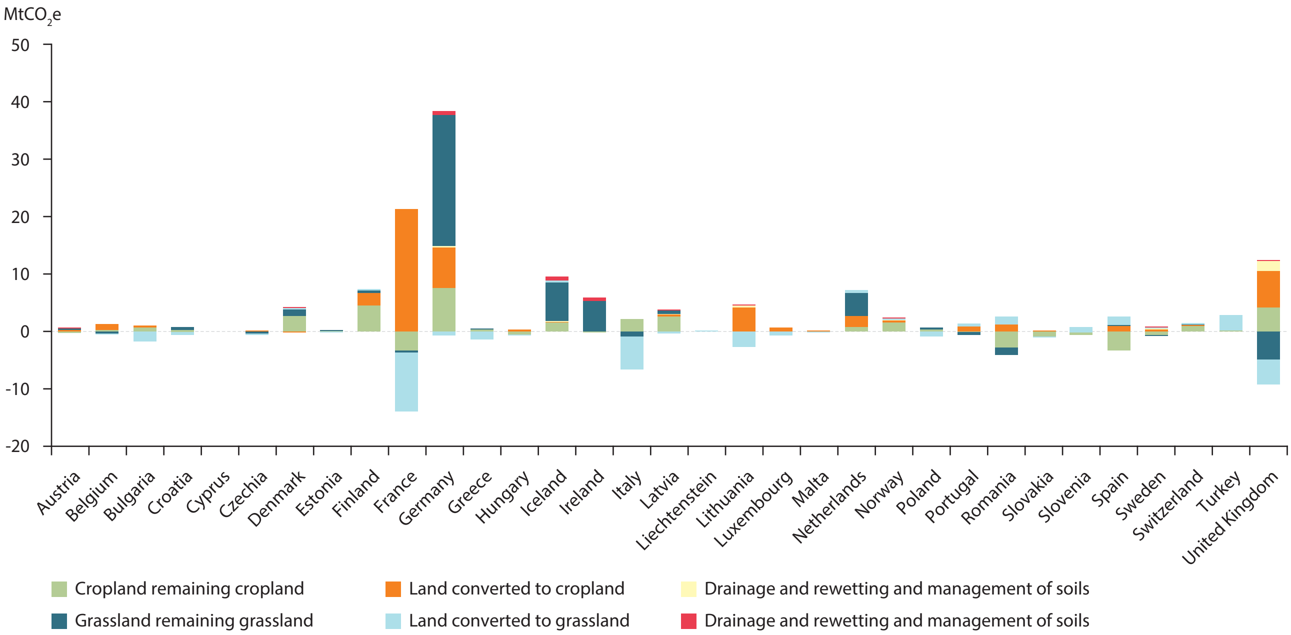
Figure 3.3 Percentage change in total GHG emissions from agriculture between in between 2016 and 1990



Notes: Total GHG emission include emissions from the agriculture sector and emissions from cropland (land remaining cropland and land converted to cropland) and grassland (land remaining grassland and land converted to grassland) under the LULUCF sector.

Source: Based on EEA (2018b).

Figure 3.4 Share of total CO_2 emissions/removals (in million tonnes of CO_2e) from agriculture-related LULUCF by category and by country in 2016



Note: CO_2 emissions/removals include LULUCF categories related to cropland, grassland and soil management.

Source: EEA (2018b).

(Eurostat, 2017a). Turkey observed increases in emissions from all source categories, due to the growth in the agriculture sector over the same period.

3.3 Removal of carbon dioxide by the agriculture sector

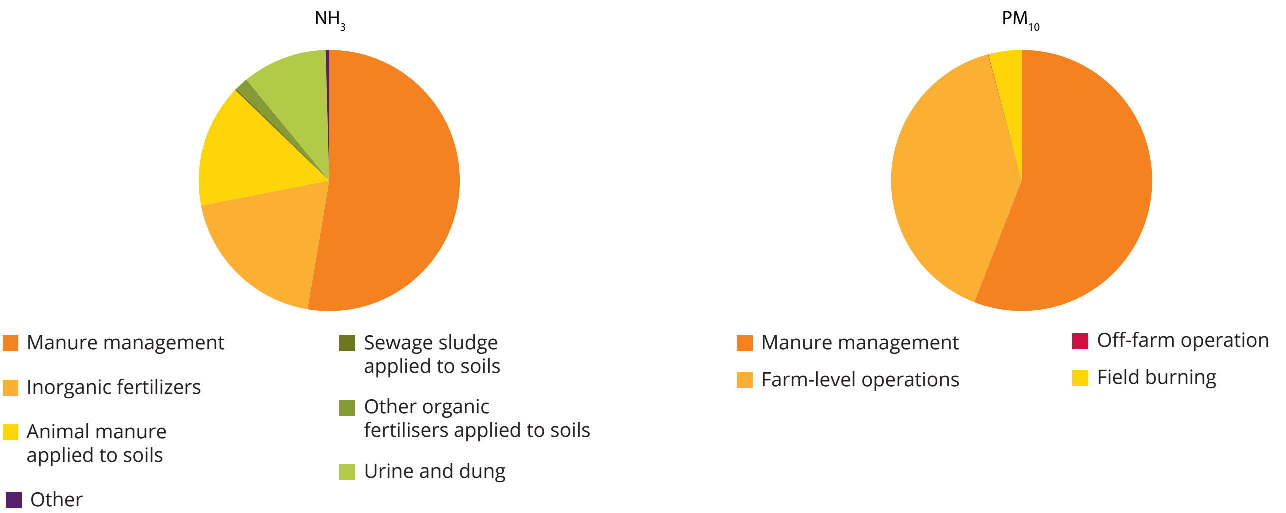
The sector can contribute to the removal of CO_2 from the atmosphere by converting between land cover types and managing the agricultural soils to increase carbon sequestration (Committee on Climate Change, 2018). These emissions and removals are reported and regulated in the EU under the Land Use, Land-Use Change and Forestry (LULUCF) Regulation (Regulation (EU) 2018/841) (EU, 2018) ([22]).

Considerable differences are observed between the EEA-33 countries in the size of both net emissions and removals contributing to the emissions/removals. The largest emitter in 2016 in the categories under the LULUCF sector was Germany, followed by France and the United Kingdom. France, the United Kingdom, Italy and Romania had the largest removals in 2016. In Germany, Iceland and Ireland, release of CO_2 from grasslands was the main source of emissions in 2016 under the LULUCF sector (Figure 3.4). Emissions from the category 'grassland remaining grassland' in these countries generally arise from oxidation of soil organic matter, where managed grasslands are located on organic soils (EEA, 2018g). In countries where climatic conditions result in large areas of organic soils, such as Denmark, Finland, Latvia and Norway, arable cultivation of these soils (category 'cropland remaining cropland') is responsible for a significant fraction of net emissions, again due to oxidation of soil organic matter. Protecting organic soils from intensive use would be beneficial from the perspective of climate action in the agriculture sector (EC, 2018c). In contrast, in some countries and particularly in eastern Europe, net GHG removals from cropland remaining cropland were reported. This is explained by the reduction in the intensity of soil management practices relative to historical levels or due to an increase in the cultivation of perennial woody crops (e.g. orchards and vineyards) (EEA, 2018g). In other countries, LULUCF emissions and removals in 2016 were largely related to conversions to either grassland or cropland. Conversions often relate to rotation between cropland and grassland on the same land, with conversion from cropland to grassland representing a carbon sink and grassland to cropland representing a carbon source (EEA, 2018b). In countries such as Lithuania and Luxembourg, these interconversions balance out. In Italy, conversions of cropland to grassland resulted in the largest net removal of CO_2. Slowing down the rate of the soil degradation and enhancing the carbon sequestration of EU soils is a win-win strategy for climate and food security that reduces CO_2 emissions and, at the same time, increases the fertility and productivity of EU agricultural land.

3.4 Trends in air pollutant emissions from agriculture

In addition to GHGs, agriculture also contributes to air pollution emissions, which affect our air quality. The sector is a primary emitter of ammonia (NH_3) and contributes to (a much smaller share) emissions of primary particulate matter (PM_{10}) ([23]).

Figure 3.5 NH_3 (left) and PM_{10} (right) emissions from agriculture



Note: Breakdown by farm management approaches based on the Nomenclature for Reporting (NFR) classification.

Source: EEA (2018c).

([23]) PM_{10} is fine particular matter consisting of fine particles with a diameter of 10 micrometres or less.

Figure 3.5 shows the NH_3 and PM_{10} emissions from different agricultural management approaches in the EEA-33. Agricultural air pollution exists mainly in the form of ammonia, which enters the air as a gas from heavily fertilised fields and livestock waste (Figure 3.5, left panel). Livestock (manure management) accounts for over half of the agricultural PM_{10}, with the majority of these emissions originating from animal feed and bedding in buildings housing livestock (EEA, 2018c). The remaining emissions of PM_{10} arise from farm-level operations, such as soil tillage and crop harvesting, and from burning crop residues and, to a lesser extent, grasslands (Figure 3.5, right panel).

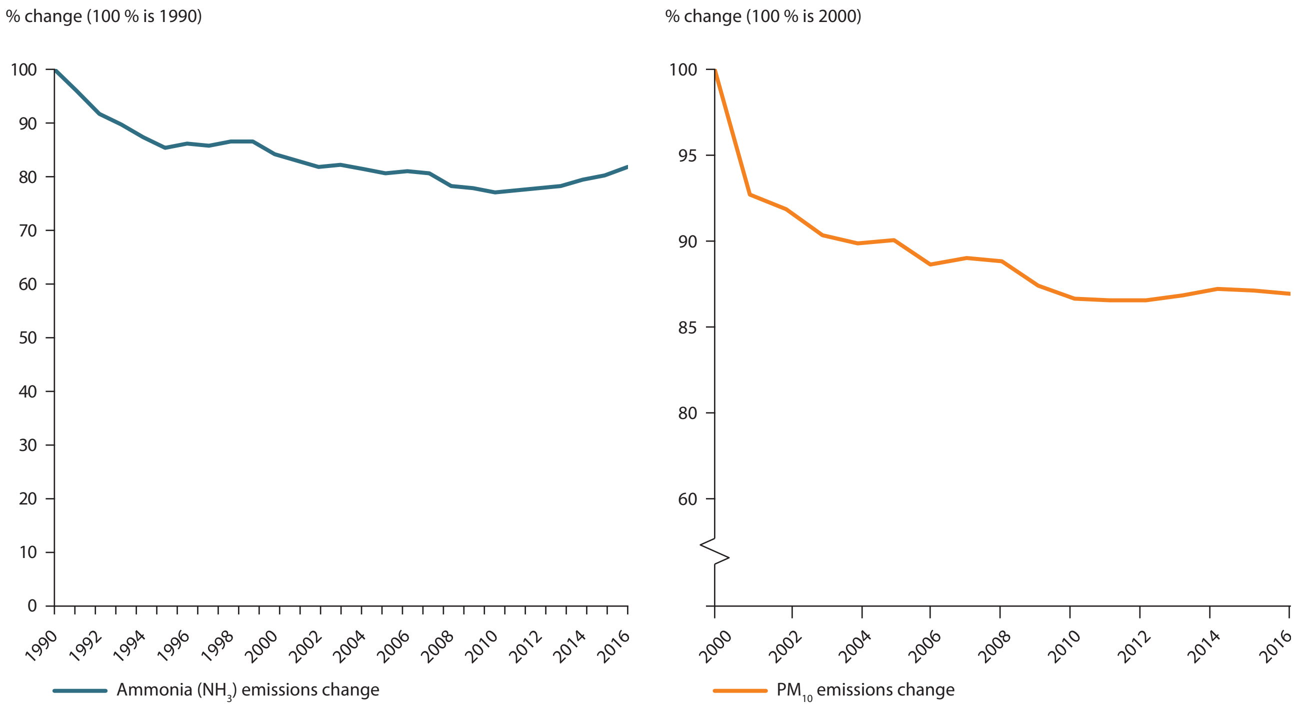
3.4.1 Reducing air pollutant emissions across Europe

Commitments to reduce emissions of the main air pollutants for 2020 and 2030 are set by the new National Emissions Ceilings Directive (NECD) (2016/2284/EU) (EU, 2016), which entered into force on 31 December 2016. The new directive transposes the reduction commitments for 2020 agreed by the EU and its Member States under the 2012 revised Gothenburg Protocol under the Convention on Long-range Transboundary Air Pollution (LRTAP Convention) (UNECE, 1979). The more ambitious reduction commitments agreed for 2030 aim to reduce the health impacts of air pollution by half, compared with 2005.

Ammonia

Between 1990 and 2016, NH_3 emissions decreased by approximately 18 % in the EEA-33, largely due to reductions in livestock numbers (especially cattle) and reduced nitrogen fertiliser use. Between 2000 and 2013, the NH_3 emissions were stable, and between 2014 and 2016 the emissions increased each year. In Germany, the rise in NH_3 emissions was attributed to increasing inorganic fertiliser application (EEA, 2018c) (Figure 3.6, left panel). The majority of countries reported meeting their 2010 NECD emission ceiling commitments: among EU Member States, Austria, Croatia, Germany, Ireland and Spain reported emissions above their ceiling, whereas Norway reported emissions above its Gothenburg Protocol ceiling (UN, 1999).

Figure 3.6 Percentage change in NH_3 emissions between 1990 and 2016 (left) and PM_{10} emissions between 2000 and 2016 (right)



Note: Change between start year and each year until 2016. Starting year for NH_3 emissions is 1990 and PM_{10} emissions is 2000.

Source: EEA (2018a).

([24]) PM_{10} emissions data are only available from the EEA viewer for the majority of EEA-33 countries from 2000 onwards.

Fine particulate matter

Between 2000 [24] and 2016, PM_{10} emissions from agriculture across the EEA-33 reduced by 13%. This was largely due to a large reduction in emissions from field burning of crop residues, alongside a 9 % reduction in emissions from livestock management (Figure 3.6, right panel).

3.5 Mitigation scenarios for the agriculture sector in the 21st century

The pace of reductions in emissions beyond 2020 is expected to slow down, falling short of the EU emission reduction target for 2030 of at least a 40 % reduction in domestic GHG emissions compared with 1990 levels (EEA, 2018g). The GHG emissions from agriculture are projected to remain stable in the absence of further mitigation incentives or changes in the amount and type of agricultural goods produced. Discussions are ongoing in the EU to adopt a new package of legislation on climate and energy to achieve this goal, together with those set out under the Energy Union. Similarly, efforts to meet longer term 2050 objectives on decarbonisation will also require a considerable intensification of efforts and include a major transformation of Europe's agriculture sector. Current efforts need to be stepped up to achieve more ambitious longer term objectives, and a long-term emissions reduction strategy in line with the Paris Agreement is needed. On 28 November 2018, the European Commission adopted a strategic long-term vision for a prosperous, modern, competitive and climate neutral economy by 2050 (EC, 2018d). The strategy brings forward a vision of a low-carbon economy that protects the planet, defends its people and sustains the economy. Consumer behaviour is highlighted as an important component in the environmental impact of agriculture. Meat and dairy products are among the most intensive products in terms of carbon emissions (i.e. they have the highest carbon footprint). The long-term strategic vision acknowledges growing consumer awareness and a change in consumption patterns that will have an impact on the delivery of a new vision for a modern and climate-neutral economy.

In support of the strategy for long-term reductions in the emissions of GHGs, low-carbon and -energy transformation pathways were analysed (EC, 2018d). This involved a modelling exercise and a literature review providing a sectoral- and technology-specific overview of the impacts on GHG emissions. The scenarios looked at covered the potential range of reductions needed in the EU to contribute to the Paris Agreement's temperature objectives of well below 2 °C and to pursue efforts to achieve a 1.5 °C temperature change. This is translated into a reduction in emissions of GHGs in 2050 (compared with 1990) of between 80 % (excluding LULUCF) and 100 % (i.e. achieving net zero GHG emissions). The relevant elements for agriculture are technical mitigation actions and consumers' diet preferences, such as the following:

- to reduce CH_4 emissions from livestock derived from enteric fermentation during the digestive process, through selective breeding programmes;
- to reduce emissions from manure by anaerobic digestion, which produces biogas that can be used to generate electricity on farm, for example;
- to reduce emissions from agriculture soil by optimising fertiliser application rates, for example by precision farming;
- to increase carbon capture in the soil by improving soil management techniques.

The mitigation potential of these actions in 2050 was calculated using the GAINS model (Amann et al., 2011). The modelling results show that the mitigation options with the highest potential to achieve results by 2050 are precision farming (low-cost options such as variable rate technology), breeding for productive, healthy and fertile livestock, and nitrification inhibitors (EC, 2018d).

Possible shifts in diet with variations in the consumption of meat, milk and egg products could reduce emissions from agriculture production significantly (Poux and Aubert, 2018; Willett et al., 2019). In the strategy for long-term reduction of EU greenhouse gas emissions, five future diet scenarios were analysed in which the consumption of meat, milk and egg products was varied. The baseline used here was based on the EU agricultural outlook (*EU agricultural outlook for the agricultural markets and income 2017-30*) (EC, 2017d) and Food and Agriculture Organization of the United Nations projections (FAO, 2018a). The scenarios also include a reduction in the generation of food waste in all EU Member States, which respects the objective of the Sustainable Development Goals (UN, 2015b) in which a target was agreed to halve, per capita, food waste generation by 2030. Results show that possible shifts in food consumption patterns could significantly reduce emissions from agriculture production. The effect in 2050 ranges from 34 $MtCO_2e$ with diet 1(highest kcal/capita/day) to 110 $MtCO_2e$ with diet 5 (lowest kcal/capita/day) and amounts to approximately 8 % to 25 % of 2015 emissions from agriculture (EC, 2018e).

4 Impacts of climate change on the agriculture sector

Key messages

- Climate change is projected to reduce crop productivity in parts of southern Europe. Increases in the length of growing seasons (due to higher temperatures) will improve the suitability for growing crops in parts of Europe — especially in northern Europe.
- The projected increase in extreme weather and climate events is expected to increase crop losses and reduce livestock productivity across all regions in Europe. In particular, an increasing drought risk in various regions in Europe is expected to reduce livestock productivity through negative impacts on grassland productivity and animal health.
- Climate change impacts on agriculture is projected to produce up to 1 % average gross domestic product loss by 2050 but with large regional differences.
- Food security due to climate change impacts in Europe will probably not be affected. Domestic agricultural production capacity and purchasing power are estimated to remain relatively high on the global market.

4.1 Introduction

Agricultural production strongly depends on climate conditions. Changes in mean temperature and precipitation, as well as weather and climate extremes, are already influencing crop yields and livestock productivity in many European regions (see Box 4.1). A projected increase in the number of extreme weather and climate events throughout Europe is expected to further increase the risk of crop losses and also impose risks on livestock production.

The impacts of climate change on agriculture vary across Europe. While increases in the length of growing seasons can improve the suitability for growing crops in northern Europe, the negative effects of climate change will lead to yield losses across Europe, mostly in southern Europe.

This chapter addresses both physical and socio-economic impacts of climate change in the European agriculture sector. Changes in mean climate variables and extreme weather and climate events affect the agriculture sector directly by lowering the yield and reducing the quality of the products. Socio-economic consequences of climate change in the agriculture sector spread across the whole economy, with macro-economic effects influencing food prices, farm incomes and ultimately food security at local, regional and global scales.

4.2 Physical impacts of climate change

4.2.1 Impacts of mean climate variables on agro-climatic variables

The increase in temperature may cause an acceleration in phenological development, with a reduced time for biomass assimilation and subsequently a lower crop yield. In some areas, the warmer climate conditions may allow the cultivation of new crops/varieties. The expected changes in precipitation during key crop development stages might counteract the negative temperature effects or, in other cases, reinforce them (Ciscar et al., 2018; IPCC, 2019).

Crop phenology and growing season length

Observations for Europe show that the increase in temperature has been significantly affecting crop phenology and the length of the growing season in most of Europe (EEA, 2017b). Diverse impacts are observed for different latitudes, crop species and varieties.

Warmer temperatures determine an earlier start to active crop growth, faster plant development and a potential extension of the crop-growing season, especially for perennial crops (Olesen, 2016). Recent studies confirm that observed changes in climate have already affected crop suitability in Europe, bringing about changes mostly for the cultivation of typical local crops, such as olives and grapevines in the Mediterranean area (Moriondo et al., 2013b, 2013a). Longer growing seasons are recorded particularly in northern and eastern Europe, as a consequence of increased temperatures and also an extension of the frost-free period (EEA, 2015a, 2017b).

A northward shift in agro-climate zones in Europe can be seen over the past 40 years (Map 4.1) and under future climate conditions over the next decades. Gradual warming over Europe has already contributed to a lengthening of the growing season and an increased active temperature accumulation. A major part of Europe will experience further northward climate zone migration: in the next few decades, the migration of agro-climatic zones in eastern Europe

Box 4.1 Summary of main climate change impacts on agriculture in Europe

Growing season and crop phenology

- An increase in the duration of the thermal growing season has led to a northwards expansion of the areas suitable for several crops.
- Changes in crop phenology have been observed, such as the advancement of flowering and harvest dates in cereals.

Water demand

- Expected increases in temperature will lead to increased evapotranspiration rates, thereby increasing crop water requirements across Europe, which are expected to be most acute in southern Europe.

Crop productivity

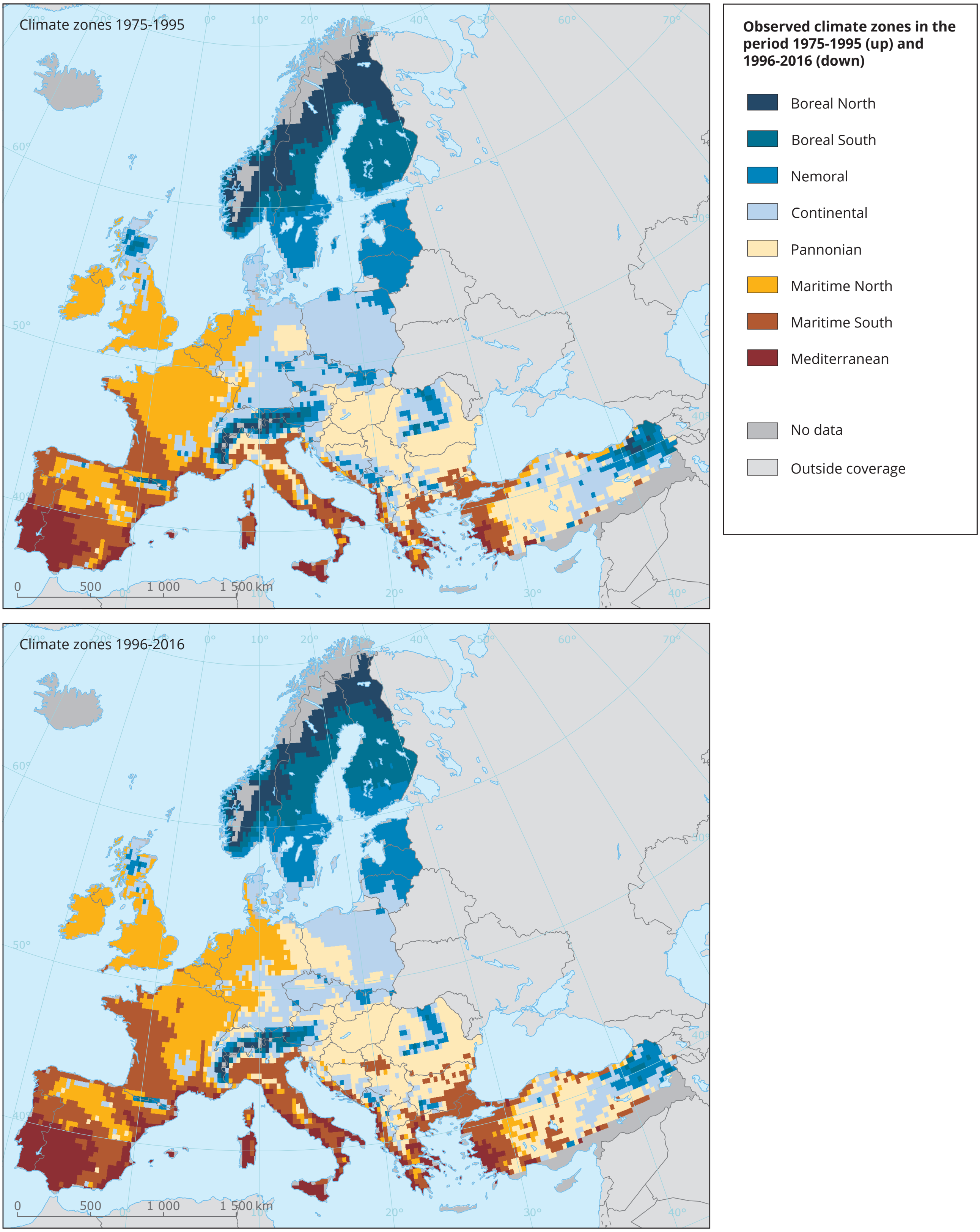
- Climate change is projected to improve the suitability for growing crops in northern Europe and to reduce crop productivity in large parts of southern Europe.
- Increases in crop productivity are expected in northern Europe, as a result of a lengthening of the growing season and a decrease in the effects of cold on growth.
- Decreases in crop productivity are expected in southern Europe, caused by faster crop development rates with subsequent negative effects, especially on grain filling.
- Extreme weather and climate events (including droughts and heat waves) can greatly reduce the yield of some crops. The projected increase in the occurrence of such events is expected to increase the risk of crop losses, with consequent increases on food prices and reduction of food security.
- Climate change is likely to extend the seasonal activity of pests and diseases and the risks associated with these effects.

Livestock systems

- Higher temperatures and the increasing risk of drought are expected to reduce livestock production through negative impacts on grassland productivity and animal health and welfare.
- The increased growing season for crops and grasslands may boost livestock system production in northern Europe, but across Europe changes in the distribution of pathogens and pathogen vectors present challenges. In addition, intestinal parasites and insect annoyance may affect animal production negatively.
- The projected increase in rainfall in northern Europe may pose challenges for grazing livestock and harvesting grass, owing to the accessibility of land and the declining soil fertility through soil compaction.

Source: Adapted from EEA (2017b).

Map 4.1 Climate zones in Europe averaged for two different periods



Note: Climatic zones based on the climate data in the period 1975-1995 (top) and in the period 1996-2016 (bottom).

Source: Joint Research Centre (JRC) based on Ceglar et al. (2019).

could reach twice the velocity observed during the period 1975-2016. Several regions of the Mediterranean might lose their suitability for growing specific crops, with northern European regions becoming more favourable areas for such crops. The potential advantages of the lengthening of the thermal growing season in northern and eastern Europe will often be balanced out by the risk of late frost and an increased risk of early spring and summer heat waves (Ceglar et al., 2019).

Changes in phenology observed for annual crops are often the result of interactions between the effects of climate change and changes in crop management that are difficult to disentangle (Rezaei et al., 2018). Increased temperatures determine a reduction in the crop grain-filling period, with detrimental effects on cereals and seed crops such as pulses and oilseed crops (Olesen, 2016; EEA, 2017b). Long-term observations available for European areas show a generalised advance in phenological phases for cereals (Garcia-Mozo et al., 2010; Rezaei et al., 2018; Oteros et al., 2015). Projections of the timing of flowering and maturity data for future decades show an advancement of 1-3 weeks by 2050, with the largest changes observed for maize and the smallest for winter wheat, especially in western and northern Europe (Olesen et al., 2012) and in Portugal (Yang et al., 2017). Compared with perennial crops, the occurrence of phenological phases in herbaceous crops is also strongly influenced by water availability and photoperiod (Garcia-Mozo et al., 2010).

Perennial species, such as olive trees and grapevines, located in specific climatic niches, are subject to a great risk from temperature increases due to climate change. An advancement in the flowering date of several perennial and annual crops of about 2 days per decade was recorded between 1961 and 2015 (EEA, 2017b). Observations show that a number of grapevine cultivars have already been growing in Denmark, Finland and Sweden for 20 years (Karvonen, 2014). More areas in northern Europe will become suitable for grapevine growth. Under the representative concentration pathway (RCP) ([25]) RCP 8.5, grapevine-growing areas are projected to expand northwards up to 55 °N by 2050 (Fraga et al., 2015). Moreover, the northwards shift of the optimal climatic zones for early, intermediate and late varieties suggests that other regions in Europe may benefit from future warmer climates with both RCP 4.5 and RCP 8.5 by 2050 (Fraga et al., 2016). For olive trees, rising temperatures in future might impact the phenological responses, that is, an advancement of flowering of between 10 and 34 days in southern Italy by 2100 (Avolio et al., 2012), which may affect crop production.

The expansion of the growing season in northern areas can result in insufficient ability to cold acclimatise. For example, for grassland, this can cause reduced winter hardiness and reduced grassland productivity (Wingler and Hennessy, 2016).

Higher temperatures can also determine an expansion in suitable crop-growing areas and the opportunity to grow second crops or cover crops. It has been proved that, under climate change, cover crops may reduce nitrate leaching and evaporation losses compared with fallow, and increase the sustainability of the system (Alonso-Ayuso et al., 2018).

Crop production

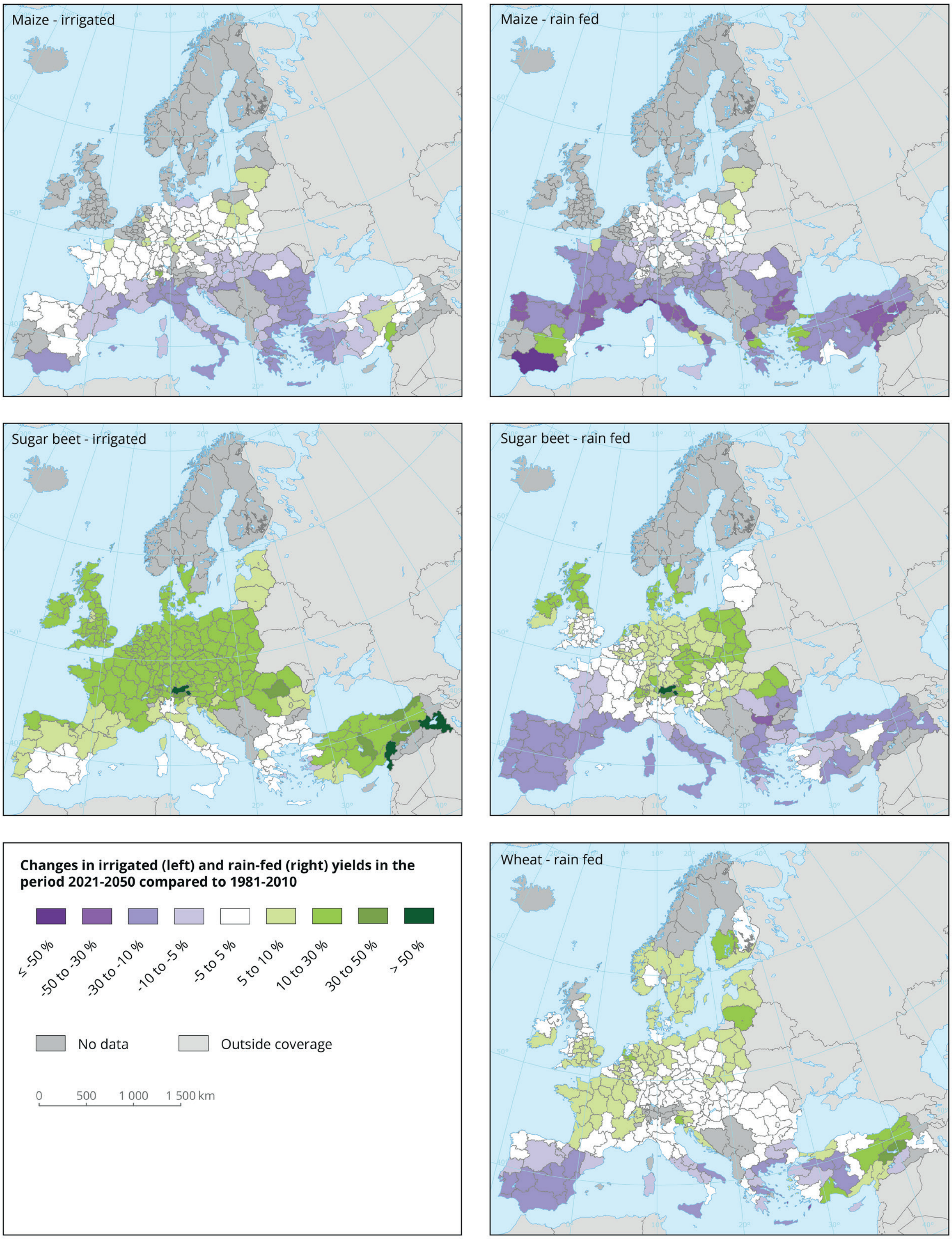
Crop production is affected by several climate-related factors, including temperature, water availability, and atmospheric CO_2 concentration. Shorter crop growing cycles, determined by warmer temperatures, have negative effects on grain filling and consequently on crop productivity because of the reduced time for biomass accumulation and yield formation (Ciscar et al., 2018).

A reduction in crop yields has been observed for various cereals in the cool growing conditions of northern Europe (Finland), as a result of an increase in temperature (Peltonen-Sainio et al., 2011). In southern-central Europe, a combination of changes in temperature and precipitation patterns negatively affected potential yield of potato and cereals (wheat, maize and barley) (Supit et al., 2010). Increases in yields were recorded for potato in Scotland between 1960 and 2010 (Gregory and Marshall, 2012), for wheat, sugar beet and maize in some areas of the United Kingdom and parts of northern-central Europe (Supit et al., 2010), and for maize in northern Europe, most likely linked to the warmer climate (Olesen et al., 2011).

Future climate projections are expected to exacerbate these observed impacts. A lengthening of the growing period and a northwards shift of suitable areas are projected as a consequence of warmer temperatures, with potential increases in crop productivity that could lead to further intensification of cropping systems, especially in northern Europe (Olesen, 2016; Ciscar et al., 2018) where climate models also project a future increase in precipitation (Kovats et al., 2014). The projected climate change conditions will determine

([25]) Representative concentration pathways (RCPs) describe possible climate futures: RCP 8.5 assumes a 'business-as-usual' approach (worst-case scenario), whereas RCP 2.6 assumes strong mitigation strategies. RCP 6.0 (medium high) and RCP 4.5 (medium low) are medium scenarios that assume some action to control emissions.

Map 4.2 **Relative changes in irrigated (left) and rain-fed (right) yields in the period 2021-2050 compared to 1981-2010**



Note: Crop yields are calculated for wheat, maize and sugar beet based on ensemble mean of 11 different climate models using high-end emission scenario RCP8.5. Wheat in Europe is not irrigated, hence excluded.

Source: Joint Research Centre based on Ciscar et al. (2018).

an increase in crop productivity by 2050 for cereal crops (such as wheat, maize and barley) and root and tuber crops (such as sugar beet and potato) (Angulo et al., 2013). A gradual northwards shift of current olive cultivation areas is also projected in the coming decades (Moriondo et al., 2013a; Tanasijevic et al., 2014).

Yield increases are projected for the period 2021-2050 for rain fed crops in central and northern Europe, while a reduction in crop yield is expected in southern Europe for all presented crops. Compared to the present (period 1981-2010), yield declines are expected in Europe for irrigated crops, except for sugar beet and maize in parts of central and northern Europe (Map 4.2) (Ciscar et al., 2018).

In cooler regions, such as northern Europe, wheat yields could benefit from warming (Iizumi et al., 2017). Improved thermal conditions under climate scenarios (RCPs 4.5 and 8.5) may lead to a yield increase in viticulture by 2050, especially in eastern Europe (Fraga et al., 2016). On the contrary, warmer temperatures could be responsible for yield losses, especially in southern European countries. For example, annual yield reduction rates of 20 kg/ha per year (RCP 4.5) or 28.9 kg/ha per year (RCP 8.5) are expected for maize in Portugal in the period 2051-2080 (Yang et al., 2017). The sensitivity of crops to temperature depends on the specific growing stage. Episodes of high temperatures experienced during flowering and/or grain-filling phases can have large negative impacts on cereal grain yields (Trnka et al., 2014; Eyshi Rezaei et al., 2015). Moreover, increases in heat accumulation (and heat stress), as projected in a study by Resco et al. (2016), could result in a lower quality of wine than the 'premium wine' currently of interest in Spain.

Crop yield can be influenced by the increased concentration of atmospheric CO_2; however, the effect of future CO_2 fertilisation is still controversial (see, for example, Fitzgerald et al., 2016; Ciscar et al., 2018). Results of Peseta III show that, in the simulations with increases in CO_2 levels, the yield declines are offset by the CO_2 fertilisation effect for C3 crops ([26]), such as wheat, sugar beet and sunflowers. However, large uncertainties exist in regard to the magnitude of CO_2 effects on yields, especially under water and nutrient limitations in the soil (Ciscar et al., 2018).

In general, the increase in atmospheric CO_2 concentration is expected to have positive effects on biomass accumulation, because of the higher photosynthesis rate (especially for C3 species) (Olesen, 2016) and crop water use efficiency, improving crops' tolerance to drier conditions (Elliott, J., 2014; Olesen, 2016; Durand, 2017). However, observations of actual crop yield trends indicate that reductions as a result of climate change remain more common than crop yield increases, despite increased atmospheric CO_2 concentration (Porter et al., 2014). The beneficial effects of CO_2 on crop yield are not always able to mitigate the negative impacts of warmer temperatures and lower relative humidity that cause a higher evaporative demand (Trnka et al., 2011; Bocchiola, 2015). For grapevines, when water is not a limiting factor (in central/northern European wine regions), enhanced CO_2 atmospheric contents, leading to a biomass increase, can mitigate some negative effects of drought (Fraga et al., 2016), but in regions with significant water stress (southern Europe) biomass production is projected to decrease.

High CO_2 concentrations may, in some cases, affect the quality of crop production, for example by reducing the protein content of C3 cereal grains (Fernando, 2015; Zhou et al., 2018) and diminishing the baking quality of wheat (Högy et al., 2013).

Water availability and water demand

Under a 2 °C warming scenario, increased water shortages are projected in southern Europe, particularly in Cyprus, Greece, Italy, Spain and Turkey, while central and northern Europe show an increase in annual water availability (Bisselink et al., 2018). Climate change is considered responsible for around 80-90 % of these projected changes (Bisselink et al., 2018). Large increases in irrigation water demand in Europe are expected under future climate conditions, ranging from small increases considering emission scenarios RCP 2.6 and RCP 4.5 (and also decreases projected over eastern Europe) to substantial increases (> 20 %) under RCP 6.5 and over 25 % under RCP 8.5 by 2100 in most of the irrigated regions in Europe (Wada et al., 2013). In contrast, some studies report projections of decreases in net irrigation requirements in areas in which a shorter crop growing cycle is expected, such as for wheat in southern Italy (Supit et al., 2010; Lovelli et al., 2010) and maize in Portugal (Yang et al., 2017).

The water-food-energy nexus, which includes the synergies and trade-offs between water, energy use and food production, will be strongly influenced by the projected increases in water demand from agriculture and energy sectors and the rising population (Gobin et al., 2017). In this respect, water demand will probably outweigh supply by 2050, unless alternative water management strategies and changes in food consumption (with implications for the types of crops grown) and energy preferences are implemented

([26]) C3 plants are temperate or cool-season plants and are the most common plants in Europe.

(Damerau et al., 2016). Mouratiadou et al. (2016) highlight the uncertainty associated with the impact of socio-economics, fossil fuel availability, climate and water policy and the necessity to integrate these aspects into water resources planning.

Pests and diseases

Climate change is likely to extend the seasonal activity of pests and diseases and cause an increase in their occurrence, especially in cooler regions where warmer temperatures may permit more reproductive cycles of insect pests (Olesen et al., 2011) and cause greater and earlier pest infestations during subsequent crop seasons, as pests may overwinter in areas in which they are currently limited by cold (Roos et al., 2011). The European corn borer (an important pest of maize) may extend its climate niche in central and northern Europe (Kovats et al., 2014). In a study by Svobodová et al. (2014), a shift in the ranges of pest species towards higher altitudes and an increase in the number of pest generations were predicted for central Europe. In contrast, in the southern regions of Europe, the number of pest generations was projected to decrease, as a consequence of insufficient humidity. Moreover, warmer climate conditions are expected to increase the risk of crop damage in field and in storages, as for instance there will be an increased risk of aflatoxins contaminating maize and wheat that may render crops unusable for food or feed use (Battilani et al., 2016). Climate change may also influence the northwards movement of the olive fly (Tanasijevic et al., 2014). Grapevine moth and a black rot fungus in fruit trees are expected to produce high levels of damage in Europe under climate change (Caffarra et al., 2012; Kovats et al., 2014). On the contrary, other pathogens, such as cereal stem rots and grapevine powdery mildew, could be limited by the increasing temperatures (Luck et al., 2011; Caffarra et al., 2012). Risks associated with the spread of pests and diseases are expected to be lower at 1.5 °C of warming than at 2 °C (high confidence) (IPCC, 2018).

Moreover, as climate change affects plant phenology and the time of flowering, the interactions between plants and pollinators may be disturbed, with detrimental consequences for crop productivity (Shrestha et al., 2018).

Livestock

Livestock production systems are of major importance in Europe, accounting for 28 % of land use in 2016 (Leip et al., 2015), with a relatively stable livestock population between 2010 and 2016. Climate change affects livestock systems directly and indirectly. Livestock is affected directly through effects on animal health and welfare. For instance, heat stress affects animal health and welfare and can lead to reduced milk production and reproductive efficiency.

Livestock production systems are mostly indirectly affected by climate change, through impacts on feed, water resources and pathogens. Climate change may lead to an increased risk of distribution and seasonality of infectious diseases, especially water- and vector-borne diseases.

The following expected trends for livestock in Europe have been reported (EEA, 2017b):

- In some areas of southern Europe, higher temperatures in combination with an increasing drought risk are expected to reduce livestock production through negative impacts on grassland productivity, which may be partly alleviated by increased CO_2 levels. Effects on animal health are also expected, as the number of days in which the temperature-humidity index exceeds the critical maximum threshold is increasing in many parts of Europe, which affects disease susceptibility.

- The extended growing season for crops and grasslands may boost livestock production in northern Europe, but across Europe changes in the distribution of pathogens and pathogen vectors present challenges.

- The projected increase in rainfall in northern Europe may pose challenges for grazing livestock and grass harvesting, owing to the accessibility of land and the reduction in soil fertility through soil compaction.

Extreme weather events can lead to infrastructure breakdown, for example, which may cause a scarcity of feed and water. Flooding may lead to less accessibility to grazing areas and increased contamination of surface water resources, which may cause diseases if used as drinking water sources for animals.

So far, adaptation has not allowed the EU livestock sector to deal successfully with major climatic events, such as the heat waves and droughts of summer 2003, 2011 and 2018. Grass-based production was severely affected through loss of productivity of fodder crops, water shortages and animal mortality, despite large imports of hay and straw in the affected regions. Furthermore, emerging diseases related to climate change-driven spatial shifts in ecosystems are affecting the sector. This is the case with bluetongue

— a virus that has now moved into sheep flocks across Europe — as climate change allowed its vector, previously confined to lower latitudes, to move into Europe (IPCC, 2014b).

The productivity losses of European livestock due to climate change are yet to be fully quantified and projected into the future (Animal Change, 2015), and initiatives in this field are ongoing. Livestock (ruminant) system modelling is complex and less developed than other areas, such as crop modelling. For example, the Joint Programming Initiative on Agriculture, Food Security and Climate Change (FACCE-JPI) knowledge hub and Macsur (Modelling European Agriculture with Climate Change for Food Security), in collaboration with the Animal Health Network of the Global Research Alliance, recently mobilised researchers from across Europe to identify current challenges in modelling impacts of climate change on livestock systems and to help improve the modelling capacity in this field. More information on the economic impacts in the livestock sector is provided below.

Reindeer husbandry

Climate change in the northern areas of Europe will have a large impact on the opportunities for reindeer herding. In Finland, Norway and Sweden, significant reindeer production is taking place on non-arable land. This semi-domesticated or free rearing animal production is significantly influenced by climate change. While reindeer herding is used to some flexibility in adapting to changing conditions, climate change is presenting new challenges. Extreme variations in weather, such as repeated freezing and thawing during winter, influence grazing conditions (where icy layers are formed), making feeding more difficult for reindeer. For instance, in Sweden, rising temperatures, increased precipitation and a change in snow conditions have already strongly impacted reindeer husbandry (Kelman and Næss, 2019).

4.2.2 Impacts of extreme weather and climate events

Climate change has substantially increased the probability of climate extremes in Europe, such as more frequent and more intense heat waves, floods, droughts and storms (EEA, 2017b). In addition, studies of extreme events in Europe have highlighted an increase in the number of warm days and nights, and a decrease in the number of cold days and nights by the end of the century (IPCC, 2018). As land and sea temperatures increase and precipitation patterns change, wet regions are becoming wetter — especially in winter — and dry regions drier, particularly in summer. The effects to agriculture vary widely among the regions. For instance, central and northern European countries are more sensitive to water excess than to drought (Zampieri et al., 2017).

Weather and climate extreme events (high temperature, heat waves, frosts, hailstorms, drought and flood) can influence total yield significantly. In 2018 various weather and climate extreme events affected Europe, estimating changes the total yield production in Europe with decreases in southern Europe and increases in northern Europe (Box 4.2).

Effects of extreme high temperatures and heat waves

Extreme temperatures can occur at different temporal (e.g. daily, monthly, seasonal, annual, decadal) and spatial (e.g. local, regional, global) scales. Extreme high temperatures can be prolonged over a period of time (e.g. several days), causing a so-called 'heat wave'. Summer heat wave events have increased since 1950 (Vicente-Serrano et al., 2014), especially in recent years (2003, 2006, 2007, 2010, 2014, 2015), and projections indicate a future warming trend in the Mediterranean area by the end of the century. In 2018, a dry and exceptionally warm spring and summer was experienced in central and northern Europe (Box 4.2).

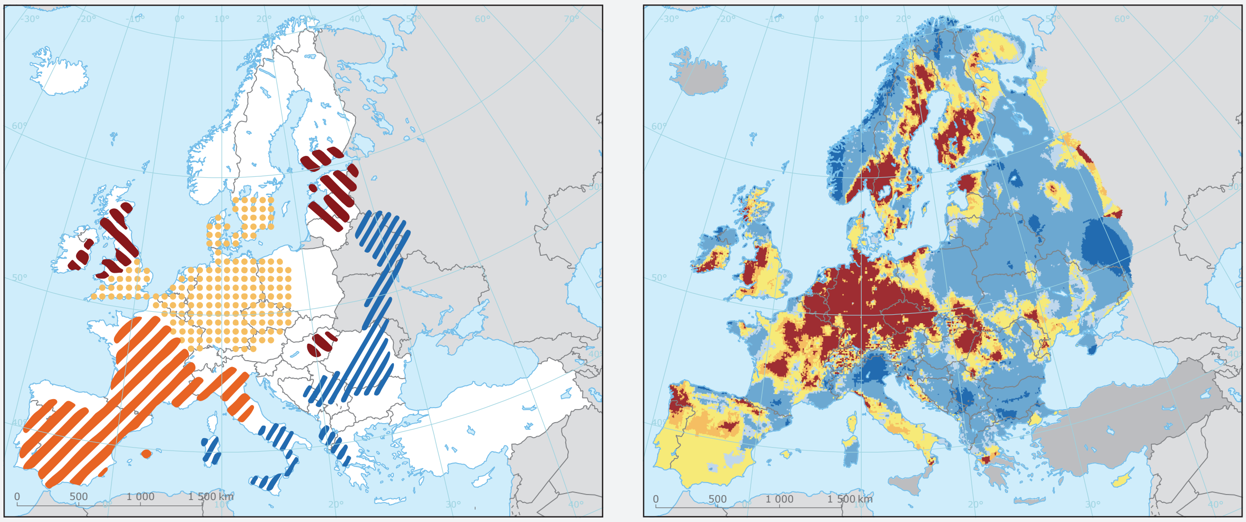
Heat stress can reduce plant photosynthetic and transpiration efficiencies as well as having negative impacts on root development, thus reducing crop yield. Even short episodes of high temperatures (1-3 days of temperature > 33 °C) during sensitive crop growth phases (e.g. flowering and grain filling) can drastically reduce crop production (Olesen, 2016), and prolonged periods of extreme high temperatures can even result in a total destruction of the crop production (Semenov and Shewry, 2011). Extreme high temperatures during the reproductive stage can also negatively affect pollen viability, fertilisation and grain or fruit formation (Hatfield and Prueger, 2015). Major effects of heat stress on wheat yield are related to a reduction in grain number because of sterility and abortion of grains (when the stress occurs during a period just before anthesis to at least 10 days after anthesis) and to reduced grain size due to cellular damage. All these effects result in a significant reduction in grain yield.

A projected increase in extreme heat during summer months may cause a shift in the crop calendar in some Mediterranean areas, by moving the cultivation of crops from the summer season to the winter season (EEA, 2017b), and determine positive changes in farm management compared with more traditional schedules. Moreover, a combined effect of extreme heat events and shorter growing seasons will imply a

Box 4.2 2018, a special year in Europe for extreme events

An analysis performed by Joint Research Centre (JRC) shows the main extreme events that affected Europe during summer 2018 (Map 4.3 left) and affected yields (Map 4.4). North Italy, France and Spain experienced a heat wave during the last 10 days of July and the first ten days of August. Central and northern Europe experienced a dry and exceptionally warm spring and summer 2018 compared to the baseline period 1981-2010. More rain as usual occurred in southern Italy Romania, Bulgaria, and parts of the Balkan region (Map 4.3 right), but without significant negative impact on crops at the national level

Map 4.3. Extreme weather events in Europe from July to September 2018 (left) and precipitation deviation during summer 2018 (right).



Areas of concern - extreme weather events, 2018

Hot and dry conditions
Rain surplus
Drought
Heat wave
Outside EEA member- and cooperating countries

Precipitation deviation during summer 2018 compared to period 1981-2010

Percentage

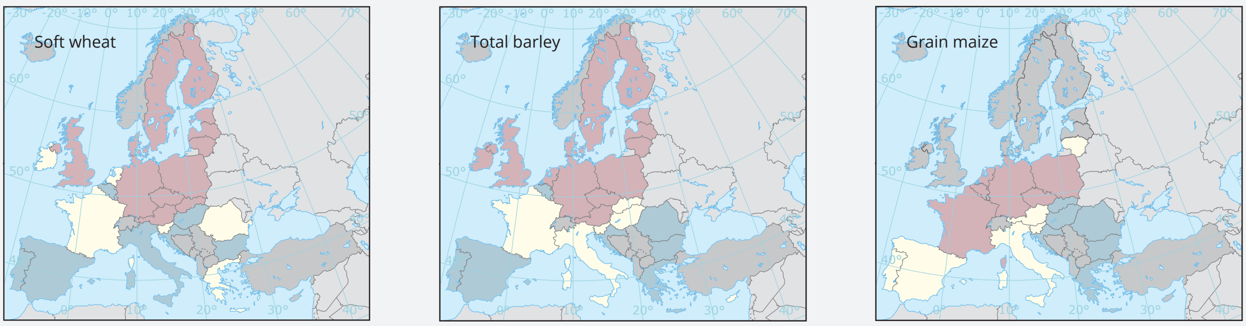
less than -20 %
-20 to -10
-10 to 10
10 to 20
20 to 100
more than 100 %

No data
Outside coverage

Source: Based on E-OBS datasets (van der Schrier et al., 2013) and JRC MARS bulletin 2018/08 (JRC MARS, 2018)

A reduction in crop yield can derive from heavy precipitation events, even if increases for some crops have been predicted for 2018 in southern Europe (Map 4.4). At the EU level, the negative impacts of the drought in central and northern Europe were, to a large extent, compensated by exceptionally high yields in south-eastern Europe, especially in the case of grain maize.

Map. 4.4. Yield forecast for 2018 for soft wheat (left), total barley (middle), and grain maize (right) in Europe, respect to the period 2013-2017.



Yield change for 2018 compared to period 2013-2017

Yield forecast 2018

Yield lower than average (less than -2 t/ha)
Yield similar to average (between 2 and -2 t/ha)
Yield higher than average (more than 2 t/ha)
No data
Outside coverage

Source: JRC MARS (2018)

loss of land suitable for agriculture (Fraga et al., 2016; Resco et al., 2016) in some areas of southern Europe. Viticulture will be also strongly challenged in the future, as a result of heat stress. Projections using both climate scenarios (RCPs 4.5 and 8.5) indicate, by mid-century, detrimental impacts on grape development and wine quality in southern Europe, leading to the need for additional measures to sustain the future of the winemaking sector (Fraga et al., 2015, 2016). In both the mid- and long-term (e.g. 2050 and 2100), olive production will also be affected because of increased demand for water for irrigation (Tanasijevic et al., 2014), heat stress during flowering, a lack of chilling accumulation needed for the blossoming phase (Gabaldón-Leal et al., 2017) and the risk of infestation with olives with fruit flies (Ponti et al., 2014).

Frost effects

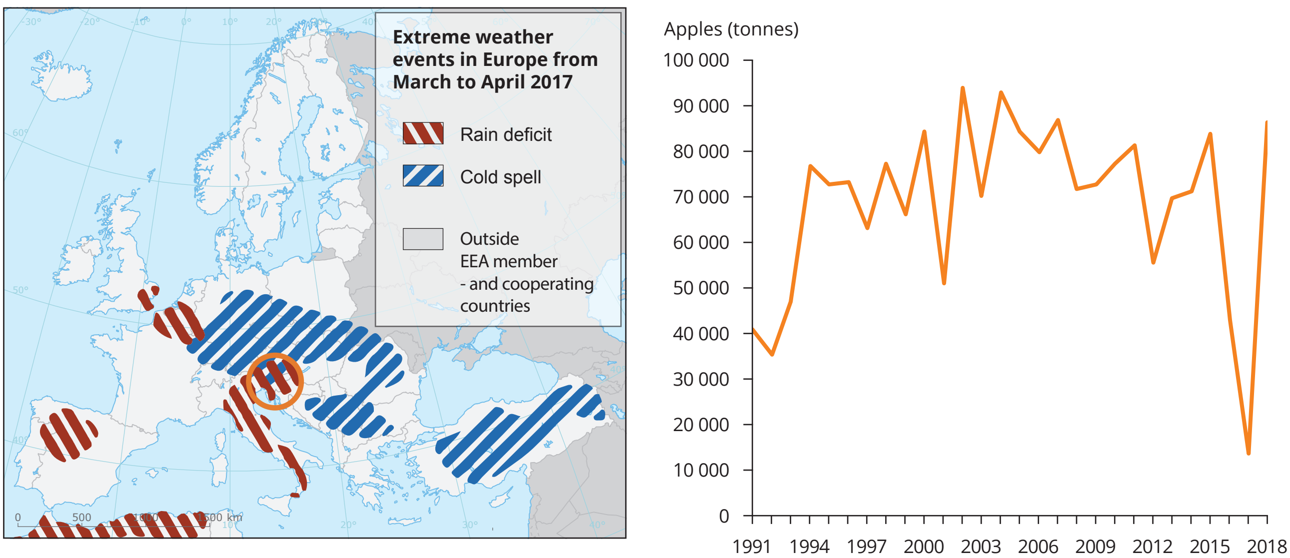
Frost is a phenomenon that leads to the formation of a thin layer of ice on a solid surface, when water vapour in the atmosphere comes into contact with the crop surface at a temperature below freezing. Owing to global warming, the number of frost-free days has increased in the last 30 years (the period 1985-2014) across Europe, especially in northern and central eastern Europe (from 0.6 to 0.8 days per year ([27])).

However, frost can adversely affect crop production and development. The extent of damage to crops depends on the intensity, frequency and duration of the phenomenon. Frost damage in wheat can occur throughout the entire growth cycle (from seedling to maturity); however, major impacts due to frost occur during the reproductive stage of growth in both spring and winter wheat (Frederiks et al., 2012). Frost effects during the vulnerable time of the phenological cycle can result in seedling death, flower sterility, abortion of partially filled grain and reduced grain weight, thereby compromising crop yield. Some cultivars are more tolerant to frost events and can survive at a canopy temperature threshold between -4 °C and -5 °C; once this threshold is reached, however, a 1 °C difference in night-time minimum temperature could increase crop damage from 10 % to 90%.

The sensitivity of crops to frost increases rapidly from the onset of flowering to the fruiting stage, when crops are generally the most sensitive. Fruit trees are especially damaged by frost, with losses accounting for more than 50 % of total frost injuries. Mediterranean plants, such as vines, may account for 20 % of the losses, but damage is infrequent. Late frost is particularly damaging to the opening buds of plants. In spring, frosts can damage yield production where the growing season is longer, as in the cooler areas of Europe. As reported by Olesen et al. (2011), the late frosts seem to be a limiting factor in a number of seasons in eastern Europe for grapevine cultivation and in Alpine northern region for spring barley production.

For example, late frosts occurred in central Europe (e.g. in Slovenia in April 2017) thus reducing the apple

Map 4.5 Extreme weather events in Europe (left) and apple production (in tonnes) in Slovenia (right) in 2017.

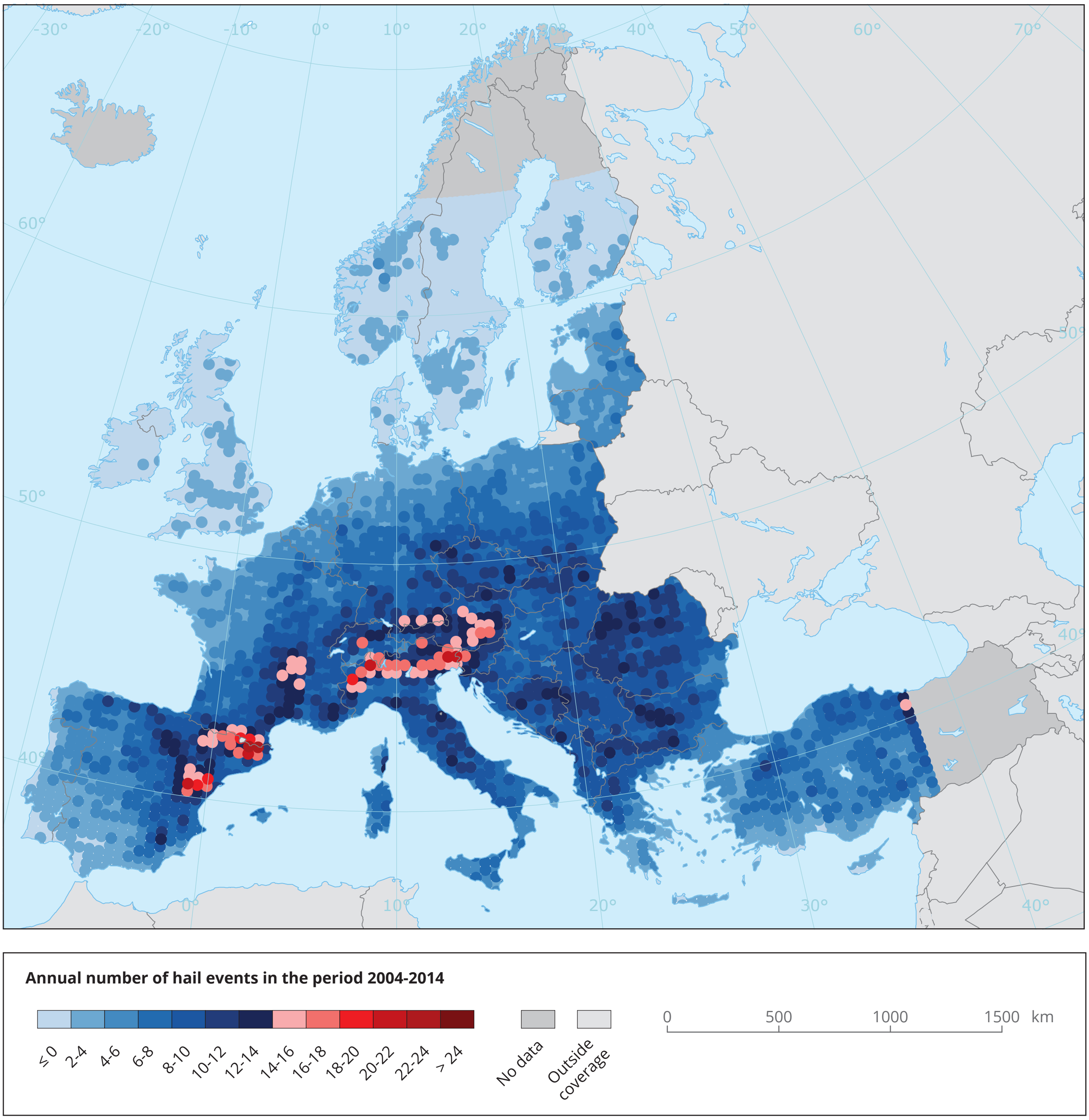


Notes: Left figure shows areas with frost and droughts events across Europe in spring and summer 2017.
Right figure shows total apple production (in tonnes) in Slovenia between 1991 and 2018. In 2017, total apple production was low due to frost and drought events.

Source: JRC MARS (2017) Statistical office of Slovenia (SURS) (2018).

([27]) Based on JRC-MARS gridded meteorological data at 25 km resolution.

Map 4.6 Annual number of hail events in the period 2004-2014



Note: Hail events are detected using overshooting cloud top detections per grid cell, on a 0.3 ° × 0.5 ° grid and averaged over the period 2004-2014.

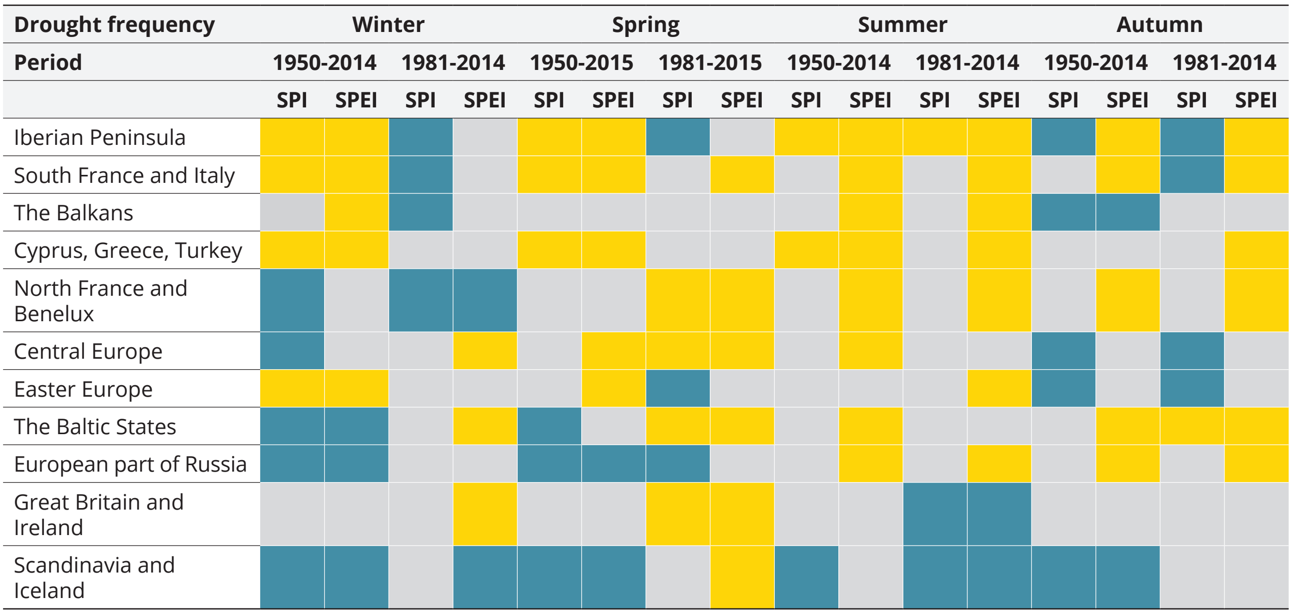
Source: Punge et al., (2017), based on Bedka (2011).

production (Map. 4.5). As a result of warming climate, a shift in the onset of flowering towards early April is expected by the end of the 21st century, posing a risk for apple cultivation due to spring frosts, especially in central Europe.

Hailstorm effects

Hailstorms cause damage to agricultural crops in most of Europe, but the most vulnerable regions to hail events are the Mediterranean area and the greater Alpine region (Map 4.6) (Punge et al., 2017). Future projections of hail events are subject to large uncertainties; however, some climate models suggest

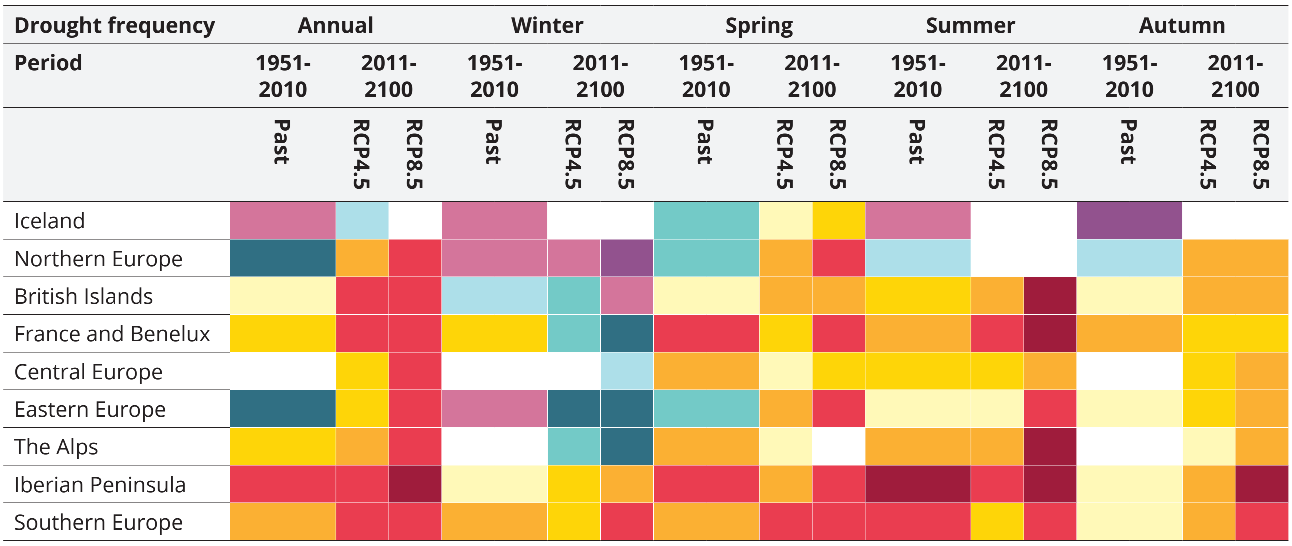
Table 4.1 Qualitative summary of past seasonal drought frequency per European macro-region



Note: The table shows the trends in seasonal drought frequency for each season and for the two periods (1950-2014 and 1981-2014). Increasing (orange), unclear (grey) and decreasing (blue) tendencies correspond to the averages for each region and variable (standardised precipitation index (SPI) and standardised precipitation-evapotranspiration index (SPEI)).

Source: Adapted from Spinoni et al. (2017).

Table 4.2 Summary of annual and seasonal past and projected drought frequency, for the European regions



- Mixed increase and decrease
- Moderate sparese increase and very sparse decrease
- Moderate increase in most of the region
- Increase in most of the region
- Strong increase in most of the region
- Strong increase almost everywhere in the region
- Moderate sparse decrease and very sparse increase
- Moderate decrease in most of the region
- Decrease in most of the region
- Strong decrease in most of the region
- Strong decrease almost everywhere in the region

Notes: The table reports a summary of annual and seasonal drought frequency from 1951 to 2010 (past) and 2011 to 2100 (future), for the European regions for the reference scenarios RCP 4.5 and RCP 8.5. Colours refer to the frequency of drought, with purple to light blue showing a decrease in drought frequency and yellow to red showing an increase in drought frequency.

Source: Adapted from Spinoni et al. (2018).

that hailstorm frequency will increase in central Europe by the end of the century (Fischer et al., 2014; Mohr et al., 2015).

Hail can cause a reduction in the production of permanent crops, such as olive, grapevine and fruit trees. Damage from hailstorms can be very costly: for example, in the Iberian Peninsula, hail is a serious concern for agriculture, with losses amounting to EUR 12.5 million in 2007 (Requejo et al., 2011). In Greece, for instance, hailstorms are one of the main causes of damage in agriculture, after frost (Dalezios et al., 2009). Losses vary considerably both temporally and regionally, and major losses are related to hail events during crops growing seasons, although variability in species sensitivity to damage is observed (e.g. tobacco and peaches are more susceptible to hail damage than maize). Hailstorms can also significantly damage greenhouses, causing serious damage to greenhouse horticulture sector.

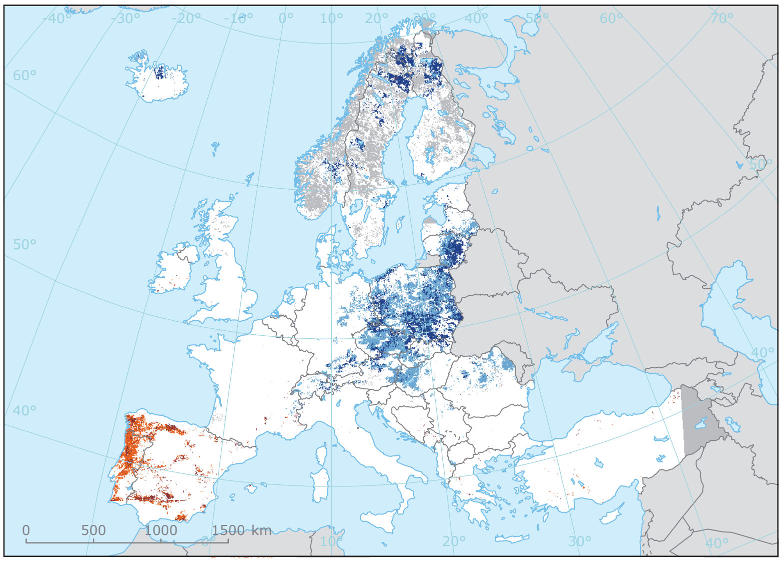
Droughts and water scarcity

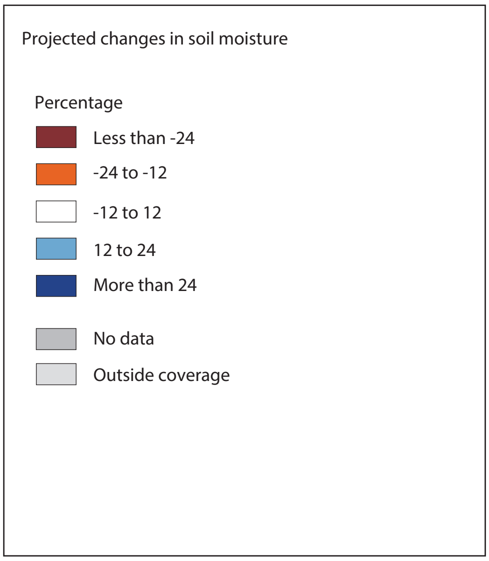
Drought is referred to as an unusual and temporary deficit in water availability, when the available water resources are insufficient to satisfy long-term average water requirements (Poljanšek et al., 2017). Historical trends in droughts in Europe report that drought frequency and severity increased over the Mediterranean area and in eastern Europe over the period 1950-2015 (Spinoni et al., 2017). Less frequent and less severe droughts occurred in northern Europe, where increased precipitation was observed, mainly for the winter season. A mixed pattern was observed in central Europe (Spinoni et al., 2017) (Table 4.1).

Future projections report an increase in drought frequency and intensity in the Mediterranean area, western Europe and northern Scandinavia by the end of the 21st century (under the moderate climate scenario RCP 4.5) (Spinoni et al., 2018), as well as a greater increase in the length of meteorological dry spells, mainly in southern Europe (Kovats et al., 2014; IPCC, 2019). However, under the more severe climate scenario RCP 8.5, more intense droughts are expected all over Europe (Spinoni et al., 2018). Droughts will be prolonged, with 1-2 days per year in the Nordic region (all of Denmark, Norway and the very south of Sweden) (Wiréhn, 2018). In the Mediterranean area in particular, including most of Portugal, Galicia in Spain, northern Scandinavia and Mediterranean Turkey , the increase in drought severity will be more pronounced (Spinoni et al., 2018). On a seasonal scale, drought frequency will increase over the entire EU continent during spring and summer (especially in southern Europe), while a decrease in drought frequency is projected in winter over northern and western Europe (Spinoni et al., 2018) (Table 4.2), under both RCP 4.5 and RCP 8.5 scenarios.

Drought is affecting the production of arable crops and animal feed in Europe, which can have an impact on farmers' income. In 2018, farmers across regions such as northern and central Europe faced crop failure, as one of the most intense regional droughts took place (Box 4.2). In addition to yield reduction, studies report that, in the upcoming decades,

Map 4.7 Projected changes in soil moisture in the period 2021-2050 compared to 1981-2010





Note: The map shows changes (in percentages) in soil moisture under the 2 °C scenario.

Source: Ciscar et al. (2018).

drought events will cause an increased demand for water for irrigation in Europe (Kovats et al., 2014; Fraga et al., 2016), reducing suitability for rainfed crop production. Irrigation demand for water for the Mediterranean area is projected to increase between 4 % and 18 % by the end of the century (for RCPs 4.5 and 8.5 climate scenarios, respectively) (Cramer et al., 2018), increasing the conflicting demands for water by different sectors (e.g. agriculture, industry, civil society).

A recent study performed by the Peseta III project analysed the propensity for damage from drought, based on future changes in soil moisture conditions and the current economic and population conditions. In the period 2021-2050 compared to 1981-2010 (using the *2 °C scenario*) the drought hazard is projected to significantly increase in south-western Europe and mostly decrease in central Europe (Carrão et al., 2016; Cammalleri et al., 2017) (Map 4.7).

Heavy rain and floods

Heavy precipitation events are becoming more frequent in most parts of Europe, including the Iberian Peninsula (Llasat et al., 2016), with strong changes observed in Scandinavia and eastern Europe, especially in winter (EEA, 2017b). Projections indicate an increase in the number of days with heavy precipitation in the period 2071-2100 in the Nordic region (about 2 days' increase per season), with an increase of up to 6 days per season (except spring) in the western part of the Nordic region (Wiréhn, 2018). Flash floods are a consequence of heavy rain falling in small catchments, and the Mediterranean region is regularly affected by such events (Gaume and Ducrocq, 2016). Europe is at major risk of flooding, with only a few countries in eastern Europe showing a decreased risk (Alfieri et al., 2017). Projections show a substantial increase in flood risk in central and western Europe for three global warming scenarios (1.5, 2 and 3 °C from pre-industrial levels), while in eastern Europe a smaller change in flood risk is expected (Alfieri et al., 2017).

Excess precipitation events can lead to crop damage and to soil erosion in agricultural fields. In addition, excessively wet soils can directly damage crops, due to anoxic conditions, increased risk of plant disease and insect infestation, and delayed planting or harvesting because it is not possible to operate machinery. Flooding and water stagnation are perceived as a problem in agricultural fields in the Boreal, Atlantic and Alpine regions and in the Mediterranean mountains, especially for winter wheat and spring barley, and for cereal fields in the Pannonia region (Olesen et al., 2011). In south-western Europe (southern France, Italy and northern Spain), widespread heavy rain has caused delays in summer crop and tree and vine crop harvesting as well as winter grain planting (Dalezios et al., 2009). A recent study (Powell and Reinhard, 2016) showed that, in the Netherlands, the number of precipitation events is increasing, with a significant impact on winter wheat.

4.2.3 Changes in land use

Changes in land use are mainly due to socio-economic drivers such as growing demand for food, feed and wood products. Climate mitigation also demands the availability of land, and this mainly occurs at the expense of agricultural land for food and feed production (e.g. for enhancing the carbon stock).

Changes in temperature and precipitation (amounts and patterns) due to climate change is affecting the suitability of land for agricultural activities. Recent studies show that observed climate change has already affected crop suitability in many areas, including Europe, especially for Mediterranean crops, such as olive and grapevine (Moriondo et al., 2013a, 2013b). In some areas of northern Europe, the projected longer growing season and the extension of the frost-free period are expected to produce positive effects, allowing the cultivation of new crops and varieties, such as grain maize and winter wheat (Elsgaard et al., 2012). The Boreal region could expect more suitable land for crops in general (about 76 %, compared with the current 32 %) by the end of the century (King et al., 2018). In the southern parts of Europe, olive trees may be cultivated in northern and central Italy (Mereu et al., 2008), in new areas of France and in the northern Iberian Peninsula (Tanasijevic et al., 2014).

Some regions in southern Europe may become less suitable for crop production, as a consequence of drier summer conditions.

Desertification

Desertification is a form of land degradation resulting in a loss of the soil's functioning ability. Land degradation is the process of turning fertile land into less fertile or non-productive land. If this process continues over time, especially in areas characterised by drought conditions, this phenomenon is called desertification. The primary cause of desertification is the removal of vegetation, which causes removal of nutrients from the soil and makes the land infertile and unusable for arable farming. Vegetation removal is mainly due to human activities (e.g. cutting down trees to allow more grazing), but it can also be associated with climate change. Desertification from human-induced land degradation can be accelerated under climate change, mainly as a result of extreme weather events, such as in the case of severe drought conditions. The main desertification processes occurring in Europe are related to soil erosion, loss of soil organic carbon, contamination, salinisation, soil compaction, soil sealing, loss of soil biodiversity and landslides.

In Europe, extensive desertification processes are occurring both in the Mediterranean and in central and eastern European countries. Europe will be affected by a rise in drought conditions and/or heavy precipitation events, thus enhancing the risk of future desertification processes. A study published in Spain showed that, as a consequence of the expected changes in aridity, the risk of desertification increases in all regions, and a good part of the territory (22 %), previously considered outside the definition of desertification for climatic reasons, would be part of arid, semi-arid and dry sub-humid areas by the end of the century. The largest increases would occur in the very high and high-risk categories, which would increase by 45.5 % and 82.4 %, respectively, by the end of the century (MAAMA, 2016).

Soil erosion

The land degradation process due to soil erosion (i.e. the rate of soil loss exceeding that of soil formation) is a natural process becoming particularly severe in the Mediterranean zone. Because of its impact on food production, drinking water quality, biodiversity, etc., land degradation is part of the EU environmental agenda. Most of soil loss in Europe derives from erosion by water (Panagos et al., 2015). The main factors affecting the rates of soil erosion by water are precipitation, soil type, topography, land use and land management. Agricultural activities such as soil disturbance, removal of vegetative soil cover and/or hedgerows, increasing field size (open fields), abandoning terraces, late sowing of winter cereals, overstocking and inappropriate use of heavy machinery can accelerate this problem. A study conducted by Panagos et al. (2015) estimated the soil erosion loss by water in Europe for the reference year 2010. Mediterranean areas showed the highest erosion rate, as well as the Alpine regions of western Austria as a result of high rainfall and steep topography. The lowest rate of loss was found in the Scandinavian and Baltic states. In addition, agricultural lands (arable lands, permanent crops, grasslands and heterogeneous agriculture lands, which cover about 47 % of the EU surface area) showed a mean soil loss of 3.24 t/ha per year, amounting to 68.3 % of total soil losses in the EU. Permanent crops showed the highest soil loss rate, especially vineyards and olive trees, followed by arable lands (spring crops, orchards and winter crops) (Panagos et al., 2015; Cerdan et al., 2010). Soil erosion also affects soil functions such as loss of fertility, excessive sediment load and reduced water retention capacity, thus increasing flood risk and leading to the desertification process.

Loss of soil carbon stock

The loss of soil organic matter is accelerated by climate change. Soil organic matter has an important role in improving soil properties (i.e. structure and porosity) and absorption capacity (water, plant nutrients), as well as in protecting against erosion. It also plays a major role in the soil carbon cycle (by increasing soil organic carbon and carbon stock capacity) (see Chapter 3). Projections for 2050, performed with different regional models and the RCPs climate scenarios, suggest an overall increase in soil organic carbon stocks in Europe under all climate and land cover scenarios but with some differences depending on the climate model and emissions scenarios.

4.3 Socio-economic impacts of climate change

4.3.1 Socio-economic impact assessment

Socio-economic impacts of climate change can have direct or indirect effects on the agriculture sector in Europe. Direct economic impacts are due to changes in crop productivity and yields, while indirect economic impacts affect the sector through changes in trade flows triggered by changes in crop production and yields. These can, in turn, spread across the whole economy of the sector with macro-economic effects on food prices, farm incomes and, ultimately, food security on local, regional and global scales. Indirect effects are usually measured with indicators of economic performances, gross domestic product (GDP) or gross value added, and with metrics measuring shares between producers' and consumers' surplus, which can result in changes in the profitability of agricultural production and in the share of income spent on food.

The future projections on economic impacts requires projections of physical effects (see Section 4.2) translated into monetary values. This translation is usually done by preparing different 'storylines' (scenarios), using several assumptions based on the number of internally consistent parameter numbers (IPCC, 2018) (see Box 4.3).

Several research initiatives have been carried out within different research communities in Europe to quantify

Box 4.3 Advances in scenario production: approaches in modelling climate impacts on agriculture

Recent developments consider, in a scenario matrix architecture, the combination of qualitative and quantitative socio-economic narratives, i.e., shared socio-economic pathways (SSPs) (O'Neill et al., 2016), with RCPs, covering the climate-forcing dimension of different possible futures. The latest developments in scenario building include the climate policy dimension with the shared climate policy assumptions (Kriegler et al., 2014).

The RCPs (Vuuren et al., 2011), focused on 2100 greenhouse gas and land use emissions, were used for the development of new climate change projections in phase 5 of the Coupled Model Intercomparison Project (Taylor et al., 2011) and their evaluation in IPCC (2014a). The SSPs, elaborated by multiple integrated assessment models (IAMs) with the support of the impact, adaptation and vulnerability community (Moss et al., 2010; Kriegler et al., 2014; van Vuuren et al., 2012, 2014; O'Neill et al., 2014), represent alternative socio-development pathways based on five reasonable narratives ([28]). Shared climate policy assumptions capture key policy attributes and describe how a world would look in a specific climate change context, implementing specific adaptation and mitigation actions to achieve a climate outcome prescribed through the RCPs (Kriegler et al., 2014).

In 2017, researchers active in the FACCE-JPI knowledge hub, Macsur, or in the Agricultural Model Intercomparison and Improvement Project (AgMIP) (Biewald et al., 2017) started a process to develop a multi-step protocol that would be useful to operationalise the generation of new storylines for European agriculture (the Eur-AGRI-SSPs), consistent with the global RCP-SSP framework. This will allow the creation of regional and sectoral storylines and scenario information products, facilitating integrated assessments at European, national and regional levels, such as the representative agricultural pathways and the European agricultural SSPs (Mitter et al., 2018).

Integrated analyses drawing on the qualitative and quantitative elements of the SSPs and climate change information from RCPs have begun to appear (O'Neill et al., 2016). Typical modelling approaches using scenario frameworks include IAMs, structural approaches, partial equilibrium models or general equilibrium models. Additional analyses rely on statistical and/or econometric tools, such as the Ricardian method ([29]).

While more coverage of variability in climate model projections has been provided in recent simulations when representing gridded yield impacts, with a few exceptions (see Box 4.3), combined approaches tend to rely on a single crop or economic model (Islam et al., 2016), which prevents a systematic comparison of results (Nelson et al., 2014a). In addition, IAMs sometimes underlie a lack of scientific understanding of the systems involved (Weyant, 2017), and assumptions made with combined and complex models are infrequently tested against observed data (Nelson et al., 2014a). Short- and long-term economic effects are not disentangled in several analyses (Moore and Lobell, 2015).

Overall, the effects of climate change on agriculture remain uncertain beyond 2050, especially owing to extreme events that are only seldom accounted for. As a result, yield variability is traditionally reported in terms of average changes only, neglecting the impact that sudden shocks and extreme changes would exert on market prices and farming rents.

Box 4.4 Modelling economic impacts on agriculture in Europe: examples of ongoing initiatives

Examples of initiatives going on to model the economic impacts of climate change on agriculture include the **Joint Research Centre (JRC)** support to the Directorate-General for Climate Action (DG CLIMA) and the Directorate-General for Agriculture (DG AGRI), through European research projects such as **Peseta** (Projection of economic impacts of climate change in sectors of the European Union based on bottom-up analysis — the third update), **Impressions** (Impacts and responses from high-end scenarios: strategies for innovative solutions), **HELIX** (high-end climate impacts and extremes) and **Avemac** (Assessing agriculture vulnerabilities for the design of effective measures for adaptation to climate change) ([30]).

Similarly, the FACCE-JPI knowledge hub, **Macsur**, has developed the TradeM model component, which intends to understand how climate change affects the long-term evolution of agricultural food prices and international trade, both in Europe and globally.

An international network of climate impact modellers contribute to a comprehensive picture of the world under different climate change scenarios, within the Inter-sectoral Impact Model Intercomparison Project (**ISI-MIP**).

Within the ISI-MIP framework, **AgMIP** integrates state-of-the-art climate, crop/livestock and advances in agricultural economic modelling with input from stakeholders.

([28]) More information is available at https://secure.iiasa.ac.at/web-apps/ene/SspDb/dsd?Action=htmlpage&page=about
([29]) For an overview of the modelling frameworks, see Wing and Lanzi (2014); Michetti and Zampieri (2014).
([30]) More details on the quoted projects are available at: Peseta (https://ec.europa.eu/jrc/en/publications-list?page=1&f%5B0%5D=im_field_identities%3A2470); Avemac (http://ies-webarchive-ext.jrc.it/mars/mars/Projects/AVEMAC.html); HELIX (https://www.helixclimate.eu/); Impressions (http://www.impressions-project.eu).

the economic consequences of climate change on agriculture (Box 4.4). Climate change impacts are normally captured by using the metric of GDP, which provides insights into the macro-economic system, giving a measure of the value of production for the agriculture and livestock sectors (see Section 4.3.4). More rarely, economic analysis considers impacts on well-being or welfare (see Section 4.3.3), for example consumers' and producers' surplus, and the costs to society (Stevanović et al., 2016). Variables commonly used to express direct impacts are the losses due to lower yields (tonnes per hectare) that, in economic assessments, are usually interpreted as variations in the total factor productivity or 'land' factor productivity. These variations induce indirect impacts via price adjustments in land-based and other markets, also affecting farm value, food systems and land use change (see Section 4.3.3), eventually influencing the overall economic performance of a region or a country. Therefore, indirect effects relate to cross-sectoral and cross-country impacts on those markets linked with the agriculture sector via trade relations (e.g. in the agro-food industry), represented via import and export flows.

It is still hard to estimate the economic impacts of climate change on the European agriculture sector, given the differences in time and geographical scales, regional grouping and the level of economic detail (EconAdapt, 2015). A chain of uncertainty ranging from model features and downscaling, emissions scenarios and impact assessment methods affect projections, and, as a result, the magnitude of responses may vary significantly across models, crop types and regions (Nelson et al., 2014a).

4.3.2 Agricultural income and welfare

Under the 2 °C increase in global temperature, a 5 % increase in total agricultural income is projected at EU level by 2050; however, this increase is mostly related to the assumed CO_2 fertilisation effect, the effects of which are very uncertain. The increase in global production and the reduction in producer prices obtained by farmers as a result of CO_2 fertilisation may decrease total EU agricultural income by up to 16 % by 2050. Looking at the distribution of the effects across space, an increase in income is experienced only by Cyprus, the Netherlands, Poland and the United Kingdom (Ciscar et al., 2018).

Despite the potentially large decrease in EU agricultural income, the income per worker could marginally rise, as a result of both farmers' abandoning the activity in specific areas (see Section 4.3.5) and structural changes (EC, 2017d).

Adaptation will have positive implications for production and prices, and therefore for incomes. In principle, successful adaptation to climate change entails improved yields or a reduction in the extent of losses and costs, supporting positive incomes. (Map 4.8, top) (Shrestha, 2014).

Applying successful technical adaptation measures across Europe may still lead to a slight income reduction in some countries because of increases in production and yields, which in turn lead to the market's adjustments in the prices of commodities (Map 4.8, bottom) (Shrestha, 2014).

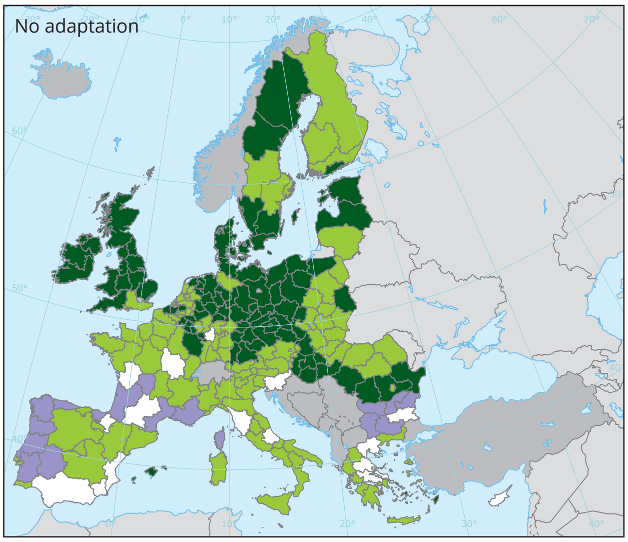
Somewhat similar results are obtained by looking at the effects on producer and consumer surplus in agriculture. The former (representing the difference between total revenues and production costs) and the latter (representing the difference between consumer's willingness to pay for a good and the actual cost, i.e. market price) are often used in economics to approximate welfare effects. The welfare loss for the agriculture sector is expected to increase for higher warming scenarios and for central Europe (Austria, Czechia, France, Hungary, Romania and Slovakia) and southern Europe (Bulgaria, Croatia, Cyprus, Greece, Italy, Malta, Portugal, Slovenia and Spain) (Ciscar et al., 2018).

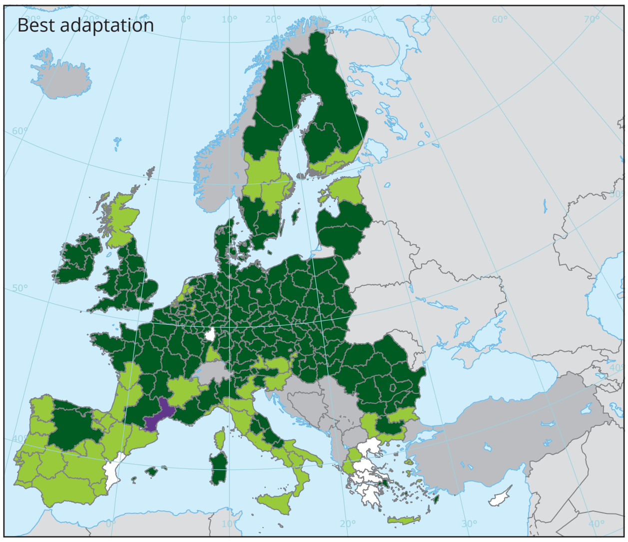
Both surpluses and income analyses can be complex due to countervailing effects, which are difficult to evaluate and entail a high degree of uncertainty, especially when estimated for the longer term.

For instance, in the case of surpluses, reduction in crop yields and greater intensification of production and expansion of cultivated areas could bring about higher commodity prices, raising producers' surplus at consumers expense (i.e. consumers' surplus is expected to decline).

The net effect on the total income depends on many other non-linear trends on demand, trade policies and liberalisation, and on impacts and adaptation in the rest of the world. For example, within the context of increasing trade liberalisation by the end of the century, larger exports from the EU would imply a higher marginal cost of production, with adverse effects on domestic prices. Gains from producers are eventually expected to be almost equivalent to losses for consumers (Stevanović et al., 2016).

Map 4.8 Income change at NUTS 2 in EU-27 in mid-2020 relative to 2004 baseline





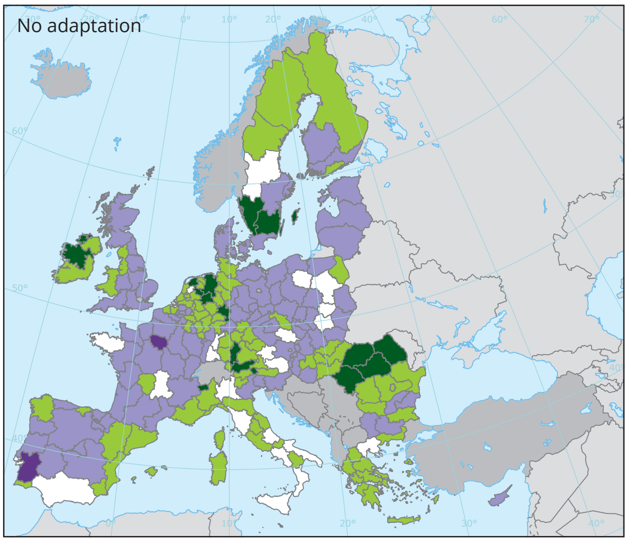
Income change at NUTS-2 in EU-27 (only supply adjustements)

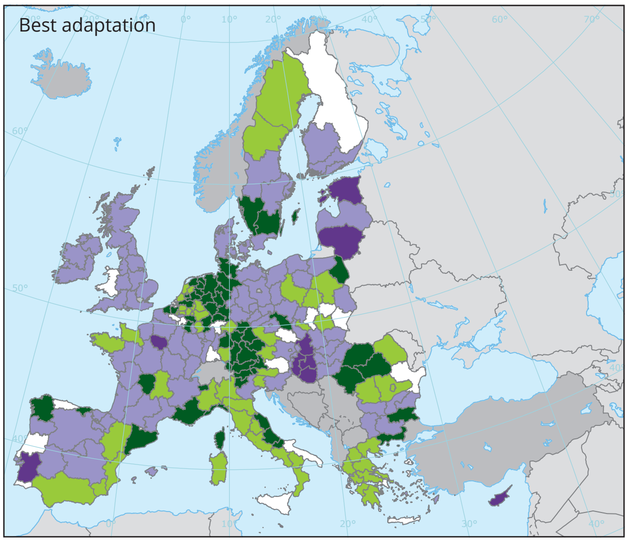
Percentage

≤ -10 | -10 to -0.5 | -0.5 to 0.5 | 0.5 to 5 | > 5

No data | Outside coverage

0 | 500 | 1000 | 1500 km





Income change at NUTS-2 in EU-27 (price adjustements also allowed)

Percentage

≤ -10 | -10 to -0.5 | -0.5 to 0.5 | 0.5 to 5 | > 5

No data | Outside coverage

0 | 500 | 1000 | 1500 km

Notes: The maps show income changes in no-adaptation and best-adaptation scenarios under climate change for EU-27 Member States (Croatia is excluded due to lack of data). The maps on the top simulate the supply response of EU agriculture to climate change, without taking into consideration market price effects (prices of agricultural commodities are assumed to be fixed). The maps on the bottom consider the adjustment of EU and world prices of agricultural commodities to supply shocks induced by climate change. Adjustments reduce incomes, offsetting production gains.

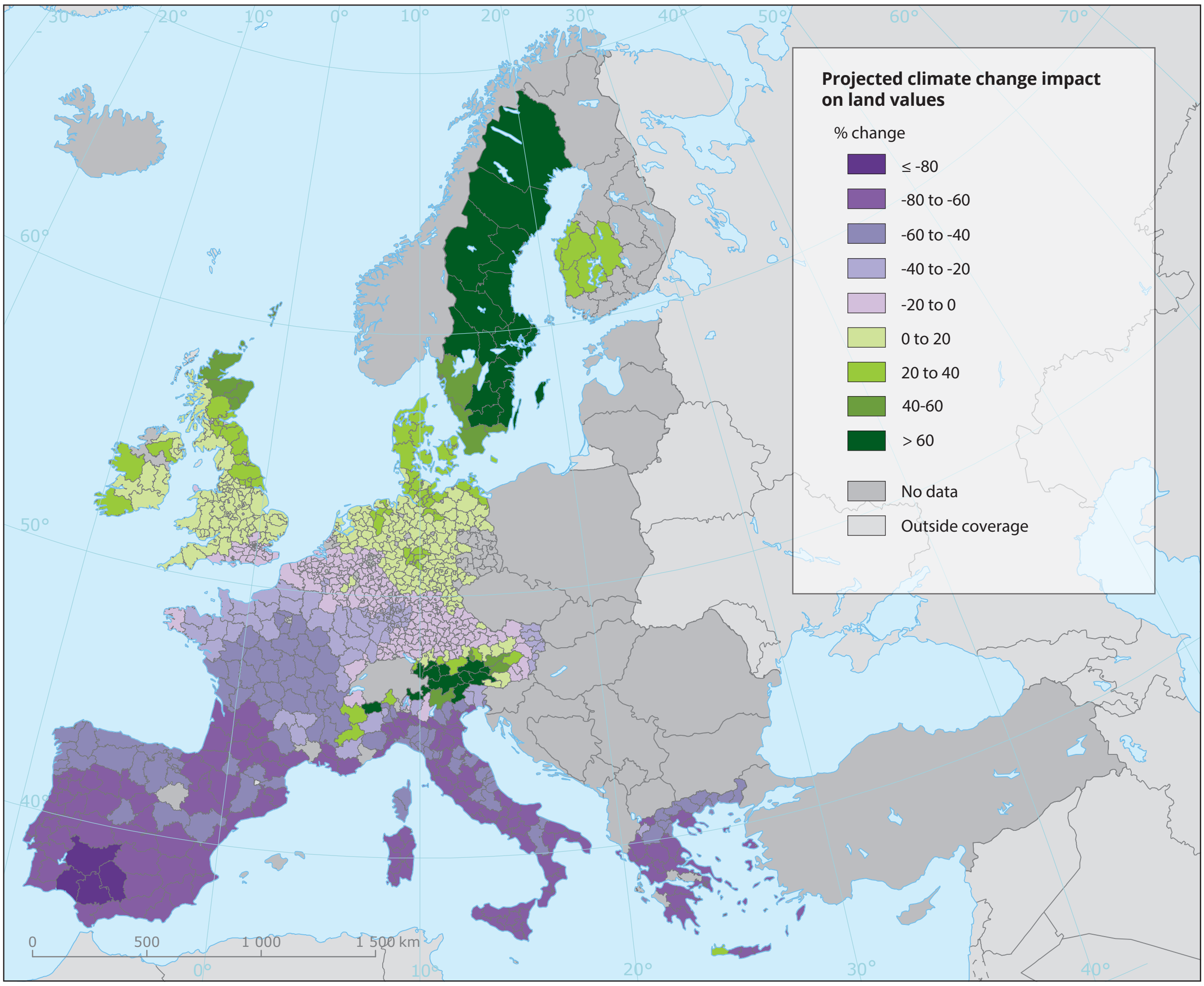
Source: Adapted from Shrestha et al. (2013).

4.3.3 *Farm and land values*

Economic impacts of climate change on agriculture are diversified across the EU. A 1 °C rise in global temperature could increase land values by 8 % in western Europe and by an even higher percentage in northern European countries (Van Passel et al., 2017). On the contrary, farms in southern Europe (Italy, Greece, Portugal, the south of France and Spain) could suffer value losses up to 9 %. According these projections, the farmland value in regions in southern Europe is projected to decrease by more than 80 % by 2100 (Map 4.9). Two thirds of the loss in land values in the EU could be concentrated in Italy, where the revenues of Italian farms are very sensitive to seasonal changes in climate parameters, especially under more severe climate scenarios (Bozzola et al., 2018). The projections show that Italy has the largest aggregate loss of farmland value, ranging from EUR 58 billion to EUR 120 billion by 2100 (34-60 % decrease) according to climate scenarios (Van Passel et al., 2017) compared to present climate (baseline period 1961-1990). These estimations are based on Ricardian analyses, which do not account for technological and policy changes and represent the climate change impacts in a static way — that is, not accounting for unprecedented extreme weather and climate events that may occur in the future (De Salvo et al., 2014).

Therefore, these quantifications could be overestimated (Bozzola et al., 2018). The effects of climate change also depend on countries'

Map 4.9 Percentage change in farmland values projected for the period 2071-2100 compared to 1961-1990



Notes: The map presents the impacts of a selected climate scenario, based on the Special report on emissions scenarios A2 GHG emissions, on each NUTS 3 region for a subset of EU countries. Several countries are negatively affected by future temperature and precipitation changes. Denmark, Finland, Ireland, Sweden and the United Kingdom benefit slightly.

Source: Van Passel et al. (2017).

adaptive capacity (Vanschoenwinkel et al., 2016), intensity of farming systems, specialisation and farm characteristics (Reidsma and Ewert, 2008; Reidsma et al., 2010).

4.3.4 The livestock sector

In addition, livestock and livestock commodities are affected by climate change both directly, through the variation in productivity and yields, and indirectly, through variations in feed prices and trade (Ciscar et al., 2018). Direct impacts on livestock are expected to change product yield and quality (Notenbaert et al., 2017), with different implications for different regions (Bernabucci et al., 2014; Bertocchi et al., 2014; Carabaño et al., 2016), and influence production costs (Wilkinson et al., 2011; Smith et al., 2014b; Garcia and Shalloo, 2015; Raboisson, et al., 2015).

While in the short term a contraction in supply can be expected for some animal products (EC, 2018i), in the medium to long term an increase in various livestock products in Europe could be induced by higher yields and lower feed costs, triggered by climate change (Shrestha et al., 2013; Shrestha, 2014; FAO, 2015). Increased production of European pork and poultry can be envisaged together with higher use (4 % and 6 % more by 2030) of cereals for animal feed (Ciscar et al., 2018; Martinez et al., 2017). Nonetheless, efficiency gains will also be required to satisfy increasing demand in the longer term (FAO, 2015).

However, reduced beef, sheep and goat meat production could result in fewer animals and lower quantities produced, and the expected trend in the major feeds for ruminant production is not favourable (Ciscar et al., 2018). In the case of grassland, despite the fact that the different sources are difficult to match and compare, there is agreement that it is declining over time. Between 1967 and 2007, European grassland declined by 7 million ha (Huyghe et al., 2014) and dropped further by around 2 percentage points between 2009 and 2015, according to land cover and land use statistics ([31]). In the future, European grassland could continue to follow this trend (Leclère, et al., 2013), in addition to being abandoned (Porqueddu et al., 2017). However, results could be influenced by the CO_2 fertilisation effect — which is expected to foster an increase in grassland production of 11 % in the EU (Ciscar et al., 2018) — and exceptions apply to northern European countries. Increased grass and wheat dry matter could positively affect wheat and milk yields in Norway, in addition to land value, which could lead to increasing profitability for farmers (Özkan Gülzari et al., 2017).

The potential positive effect of CO_2 fertilisation also has implications for trade relations and, therefore, for producer prices. Not to consider its effect would make some imports cheaper and the export environment for some products more favourable. Conversely, its effect would make feed prices cheaper and would lower producer prices, as a result of an increase in imports (Ciscar et al., 2018). Analyses of impacts of climate change on livestock are few in Europe (IPCC, 2018) and usually do not consider the effects of adaptation of livestock systems and extreme events such as droughts (Harrison et al., 2016).

4.3.5 Land use change, land displacement and emerging dynamics affecting land use

Land use and land cover changes in Europe are influenced by interactions between different agriculture practices and by interactions between different socio-economic sectors; therefore, projections of land use and land use cover are difficult to make under increasing uncertainty related to socio-economic and climate forcing (Prestele et al., 2016; Holman et al., 2017). Land use change, resulting from management decisions, overlaps with market-mediated or policy-driven indirect effects and with climate-induced price variations (IPCC, 2018).

Despite the differences across model assumptions and parameterisation (Schmitz et al., 2014; Robinson et al., 2014), there is a general consensus that the agricultural and forest area will be shrinking by 2050, with larger effects in southern and central Europe due to climate change (Holman et al., 2017). Agricultural land outflow is expected to continue at a rate of 0.2 % utilised agricultural area (UAA) per year until 2030. As a consequence, arable land will probably decrease by 3 % between by 2030 (EC, 2017d). More generally, as a high-income area, Europe is expected to require a higher amount of productive land per capita (land footprint) than low-income countries.

The negative impact on cropland can be partly offset by socio-economic dynamics such as changes in production efficiency in the agriculture sector and adaptation actions, in addition to positive effects of climate change in northern European areas.

The rising demand for land by 2030 can also be partly accommodated by agricultural intensification and

([31]) Eurostat statistics are available online (http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=lan_lcv_ovw&lang=en).

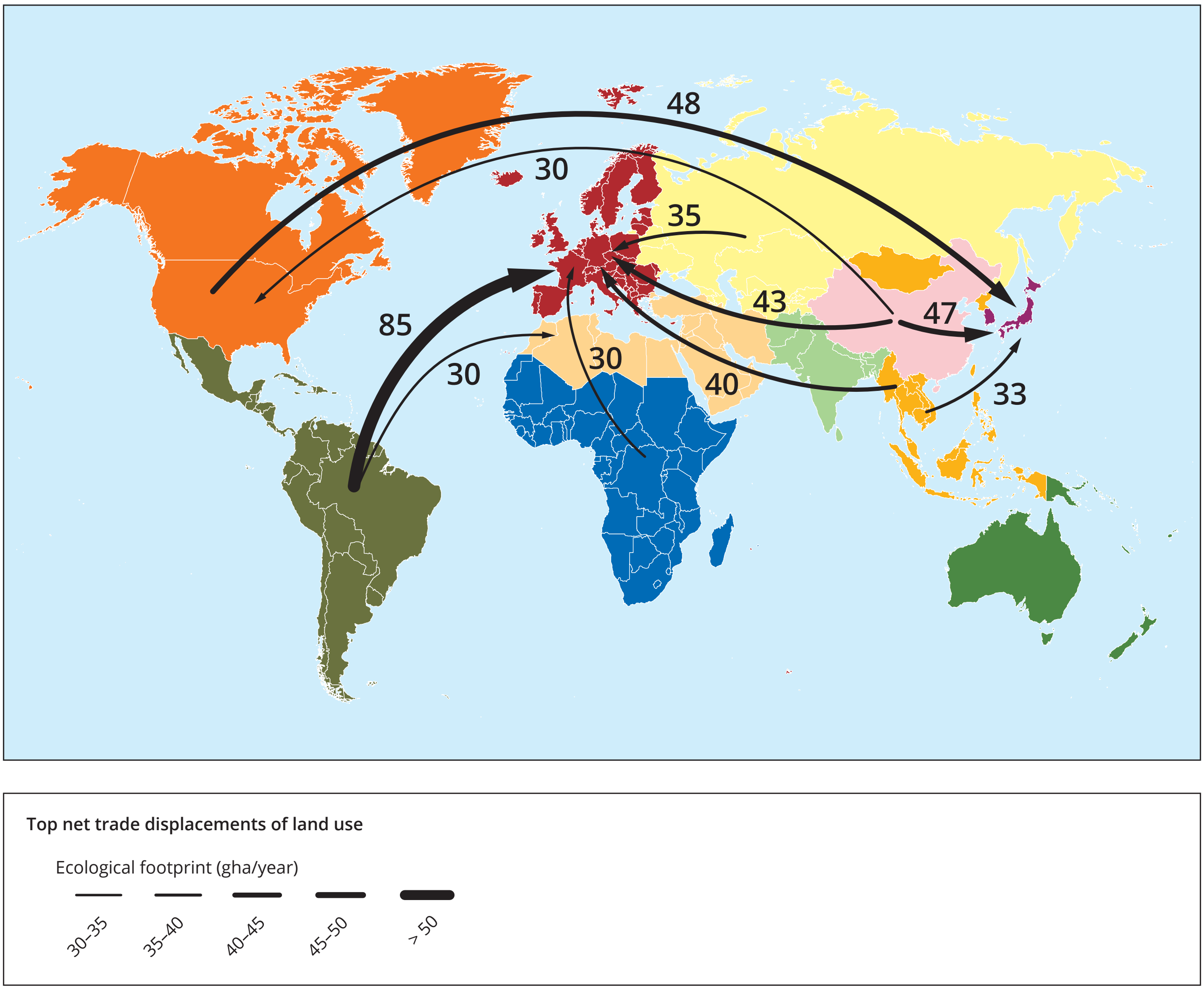
expansion on to available uncultivated land (Byerlee et al., 2014), which is concentrated in eastern Europe. The rest will probably be satisfied through land use displaced through international trade (land that Europe would use to produce internationally traded food, fibre and fuel products), raising trade from land-abundant to land-scarce countries (Map 4.10). Despite the fact that commercial relations can function as market-driven adaptation strategies, this land displacement could potentially increase the European land footprint (Steen-Olsen et al., 2012; Weinzettel et al., 2013). Finally, it is worth mentioning that land grabbing is a phenomenon that has also recently been observed within the EU, mainly in eastern EU Member States.

4.3.6 Macro-economic impact of climate change on agriculture: gross domestic product and price effects

Gross domestic product

Yields may change significantly across the EU Member States by 2050 (see Section 4.2). However, the projections for GDP in the agriculture sector show a relatively small change (around 1 % by 2050) depending on the climate scenario and whether or not the CO_2 fertilisation effects are considered (Ciscar et al., 2018). The total economic loss for agriculture in Europe due to climate change depends on the emission scenarios, with losses increasing with the

Map 4.10 Top net displacements of land use globally



Note: Displacement is calculated as exports minus imports (the land use displaced to other countries through imports), with the arrows indicating the direction of product flow. Countries are aggregated into 11 regions (presented in different colours). Units are in million global hectares (gha) per year, a unit used to measure ecological footprint.

Source: Adapted from Weinzettel et al. (2013).

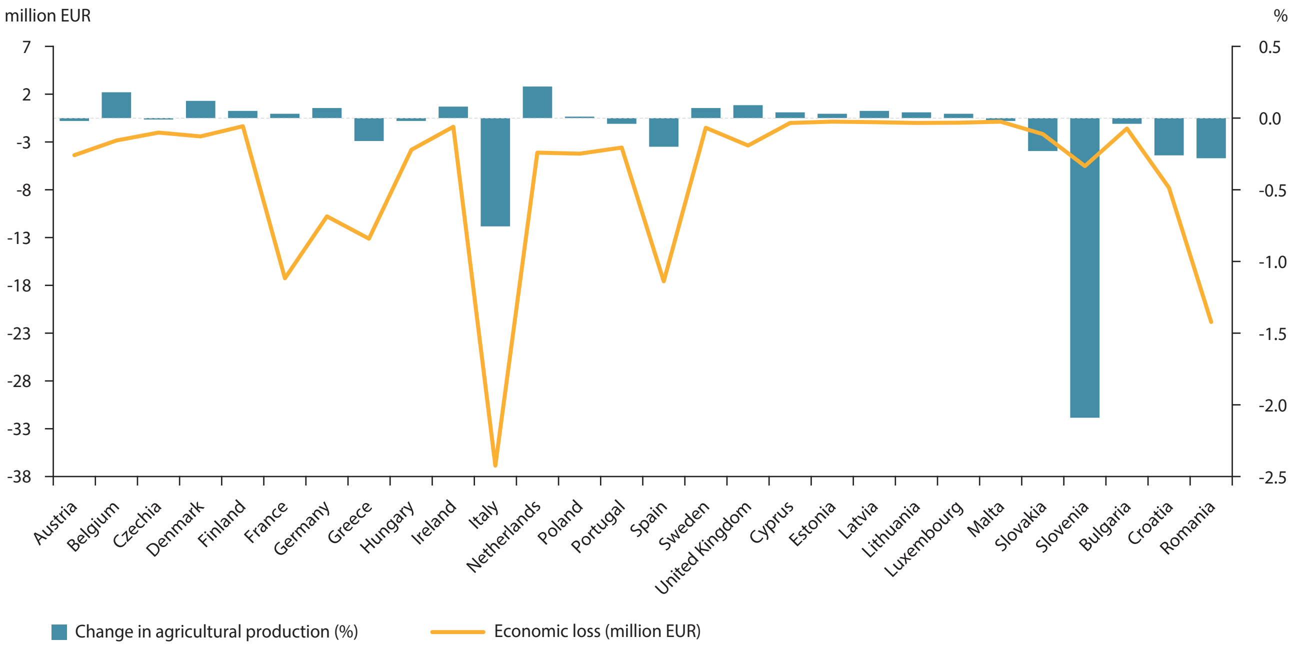
level of warming (Wiebe et al., 2015; Berry et al., 2017). But these results can be significantly influenced by market mechanisms (e.g. changes in crop prices, substitution of factors and changes in competitiveness in response to yield changes), which can then soften the initial large impacts of climate change on agricultural production (Martinez et al., 2017) ([32]).

Moreover, the changes in GDP are much larger in all emission scenarios when looking at the regional levels. Northern EU Member States could potentially increase GDP; the Member States in central Europe could see moderate changes, while southern Member States could experience a decrease in GDP. Overall, GDP effects follow production changes that mirror yield variations with CO_2 fertilisation further boosting the cumulative effects (Fernández and Blanco, 2015; Blanco et al., 2017; EC, 2017d).

Additional influences on production and yield change may originate in those European countries in which the impact of soil erosion is particularly severe (Panagos et al., 2018). The estimated direct cost of agricultural productivity loss in the EU due to soil erosion (i.e. land suitability; see above), which also has a climatic component, is around EUR 1.25 billion (between 2010 and 2020), corresponding to 0.43 % of the EU's total agriculture sector contribution (Panagos et al., 2018). Erosion is expected to increase in the future due to more extreme rain events but also sectoral changes such as increased farm size, heavier machinery and increased compaction play a role (Panagos et al., 2018).

The negative impact of soil erosion on crop productivity is mostly experienced by Mediterranean countries (Italy, Greece, Spain and Slovenia) and particularly affects rice and wheat, as these are the dominant crops in the region. Other types of crops, such as rye, being mostly cultivated in northern and central European countries and less affected by erosion, show modest losses. When the physical impacts are translated into economic terms, despite the fact that Italy is less affected than other countries in physical terms, they represent very high economic losses (Figure 4.1). Current soil erosion findings are based on European-scale spatial data. It should be noted that local studies using high-resolution data and local knowledge can lead to different results. In the case of Slovenia, for instance, local studies show much lower losses due to erosion compared with studies at European level, mainly because these

Figure 4.1 Changes in agricultural production and economy losses in the EU due to soil erosion



Note: The figure shows changes in agricultural production in percentages and GDP (million euros) in 2020 (compared with 2010) across European countries due to soil erosion, showing differences between direct and indirect effects. For instance, in terms of percentage physical losses, Italy is almost three times less affected than Slovenia. Nonetheless, this translates into greater loss in Italy than in Slovenia because a greater proportion of Italian land is subjected to severe erosion (33 %) and it is a bigger country than Slovenia.

Source: Adapted from Panagos et al. (2018).

([32]) Results are partly motivated by the methodological approach followed by the studies, often based on computable general equilibrium modelling. In these models, the importance of economic impacts is strongly related to the weight of each sector in GDP production, and that of agriculture in the EU is rather small.

studies include data at a higher spatial resolution, available at the local level only (Komac and Zorn, 2005).

Price effects

The combination of socio-economic and climate-induced price variations is expected to be complex and extensive, geographically and temporally variable. The thing that is critical in this respect is the understanding of how climate-induced food price shocks transmit across sectors and national borders, such as the effect of mitigation policies on income, as a result of the GHG pricing (IPCC-FAO, 2017). While price shifts make it hard to adjust farmers' activities to produce higher value crops, the increase in price volatility leads to greater uncertainty about the future, preventing investments in agriculture, with effects on the amount and quality of production (Porter et al., 2014). At the same time, price changes can influence production and access to food in Europe (IPCC, 2018). Although food security in the EU will probably not be an issue, the increase in food requirements and the expected modest rise in demand (EEA, 2017c) could exert pressure on food prices (price shift) and volatility in the coming decades (Nelson et al., 2013, 2014b). A similar impact can be observed because of farmland grabbing and land concentration. The introduction of large corporations can drive down the price of agricultural commodities. To compete, local farmers see themselves forced to lower their prices too, tightening their margins and returns (Kay et al., 2016). In addition, trade dynamics outside Europe will also affect European agriculture, in a context characterised by economic globalisation (Box 4.5).

Crop producer prices are expected to vary between -3 % for cereals and +5 % for other arable field crops in a warming scenario of +2 °C by 2050, consistent with a high-end RCP 8.5 emission scenario. Introducing the CO_2 fertilisation effect is assumed to trigger greater competition on the world markets, increasing EU domestic production, but it may instead lead to a price decrease for all agricultural commodities (e.g. 20 % decrease in the cereal price). Corresponding lower animal feed costs may have a positive impact on the livestock sector's production and income (Ciscar et al., 2018).

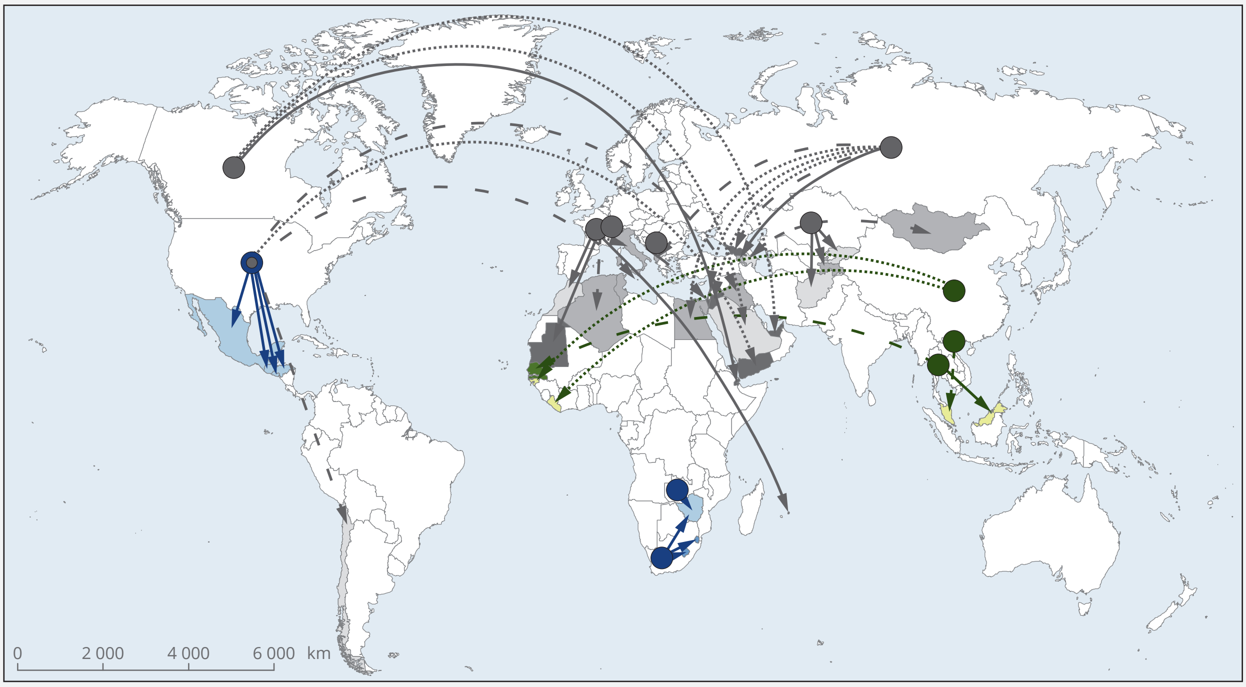
4.4 Selected case studies

Case studies presented in Boxes 4.6-4.10 to illustrate observed and projected effects of climate change in different regions in Europe. Two examples focus on the impacts of climate change on grapevines, exploring the effects on wine production and quality (Box 4.6), and wine phenology (Box 4.8). Impacts on olive oil are presented in Box 4.7. An analysis of the water footprint of arable crops is reported in Box 4.9, and an example of the impact of extreme weather events in 2018 on commodity prices is shown in Box 4.10.

Box 4.5 Trade relations and price impacts outside Europe affecting European agriculture

Most of the countries receive their agricultural imports from just a few dominant producing states or even from just one (Map 4.11). Given the geographical concentration of production, climate-induced changes and extreme weather events occurring in key producing regions can result in food price increases in Europe and worldwide.

Map 4.11 Major crop trade flows



Major crop import flows for caloric trade dependent countries

Import dependency ratio

Maize

Rice

Wheat

≥ 50 %

50-75 %

< 75 %

Import share

< 50 %

50-75 %

> 75 %

Exporter yield

Maize

Rice

Wheat

Note: The map shows crop import flows for caloric trade dependent countries. The various colours indicate the crops imported. Deeper shading indicates a higher import dependency ratio. Import arrows connect each country to its major supplier. The thicker the arrow, the higher the share the exporting country has in the import volume of that country.

Source: d'Amour et al. (2016).

Climate change consequences can then become stressors that ignite a mix of underlying causes that can even erupt into social revolutions. For example, the severe heat wave in the summer of 2010, by destroying about 30 % of Russia's grain harvest, led to an export ban on wheat by the Russian government, therefore global wheat prices increased (Coghlan et al., 2014; EEA, 2017b) and had greater effects on countries that had a higher trade dependency on wheat (d'Amour et al., 2016).

Along the same lines, starting from the winter of 2006/2007, the severe drought in Syria, exacerbated by rising temperatures, caused extensive crop and livestock failure in the period 2007-2010: wheat production failed, the agricultural share fell to 17 % and livestock mortality reached 85 %. Food prices increased by 40 % in the region (Gleick, 2014) and this contributed to starvation in Syria (Kelley et al., 2015). Climate-driven price hikes in agricultural commodities contributed to start of the 'Arab Spring' (Werrell and Femia, 2013; Perez, 2013).

Box 4.6 Wine production and quality in Spain: exploring adaptation choices

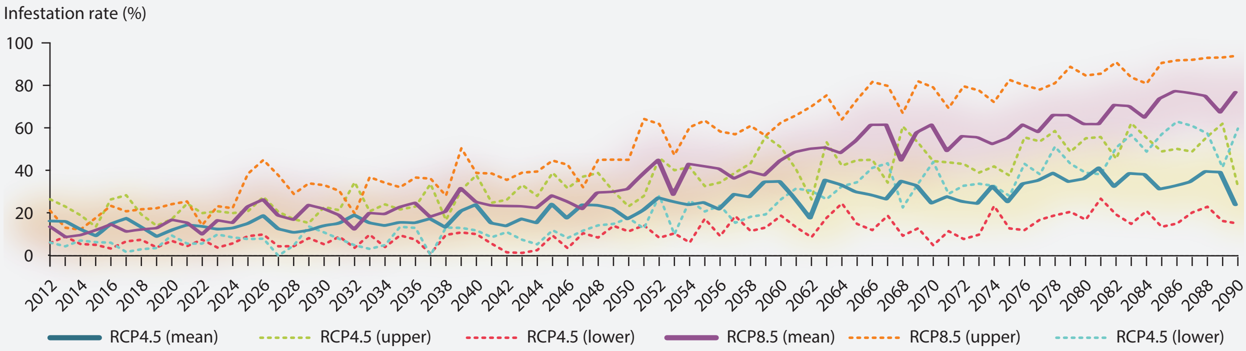
A study conducted in Spain (Resco et al., 2016) analysed the main reasons for concern for diverse areas of the country due to climate change and explored the adaptation choices for grapevine cultivation. The territory was divided into four major agro-climatic zones, and the analysis showed that northern regions are mainly affected by late spring frost, while southern regions mainly suffer extreme heat in summer. Recurring drought episodes also occur in most of the territory. Significant impacts on wine production and quality are then expected mainly in southern Spain, owing to increased levels of heat and more severe water stress conditions. Adaptation efforts are needed to reduce negative impacts, but a different level of adaptation is required across Spain. Less adaptation effort is required in the northern regions, while more effort to maintain stability in wine production and quality is needed in the southern regions, especially in the Castilla-La Mancha and Andalusia regions. In these regions, irrigation might become mandatory, as might the need to introduce varieties suited to a warmer climate. However, opportunities may arise as a result of an expansion of viticulture in the northern region, thanks to a decrease in frost damage, with resulting improvements in wine quality, as these regions will be more suitable for the cultivation of new premium wines varieties as a result of an overall increase in temperature.

A recent EU project, VISCA (Vineyards Integrated Smart Climate Application) ([33]), started in May 2017 with the aim of making European wine industries resilient to climate changes. The project will provide both a climate service and a decision support system that, by integrating climate, agricultural and end-user specifications, will help to design medium- and long-term adaptation strategies for climate change. Real demonstrations with end users at three sites in Spain, Italy and Portugal are planned to validate the project tools and help wine companies to develop the capacity to make well-founded decisions for an appropriate crop planning.

Box 4.7 Olive oil production and pest infestation

Woody perennial crops are likely to be highly vulnerable to climate change, and long-term management strategies are crucial for reducing negative effects on crop production and phenology. The Agricultural Climate Advisory Services (AgriCLASS) Copernicus Climate Change Service (C3S) project calculated bioclimatic indicators and crop impact indicators to support agricultural applications. Olive trees represent a high value European crop (i.e. up to 75 % of global olive production), but they are vulnerable to pest infestation, which reduces crop production and virgin olive oil quantity and quality. A pest impact indicator was developed to link the growth cycle of the *Batrocera oleae* (Rossi) fruit fly population to changes in climate conditions in Tuscany (Italy). The study area represents 63.4 % of the national area for the production of high-quality extra virgin olive oil. The study revealed that warmer temperatures (especially higher minimum temperatures during the winter season) and extreme weather events (drought) can alter population dynamics by modifying the insect's rate of development, reproduction and mortality (Marchi et al., 2016). These conditions will lead to reduced olive yields and an increase in pest infestation (Figure 4.2). Results revealed that winter temperatures could be a useful early warning signal for predicting pest dynamics and for helping farmers in planning site-specific management options during the early stages of infestation, to avoid or reduce severe loss of crop production. Therefore, knowledge of the climatic variables affecting pest temporal and spatial development is an important factor for supporting management strategy at farm or regional level.

Figure 4.2 Olive infestation by fruit fly in early summer in Italy.



Notes: Spring Flight is the calculated day of first annual appearance of *B. oleae* (olive fruit fly) in spring. AgriCLASS has used this data to calculate the presence of B. oleae in relation to olive growing in Italy. Mean values and lower and upper limits based on several models are presented.

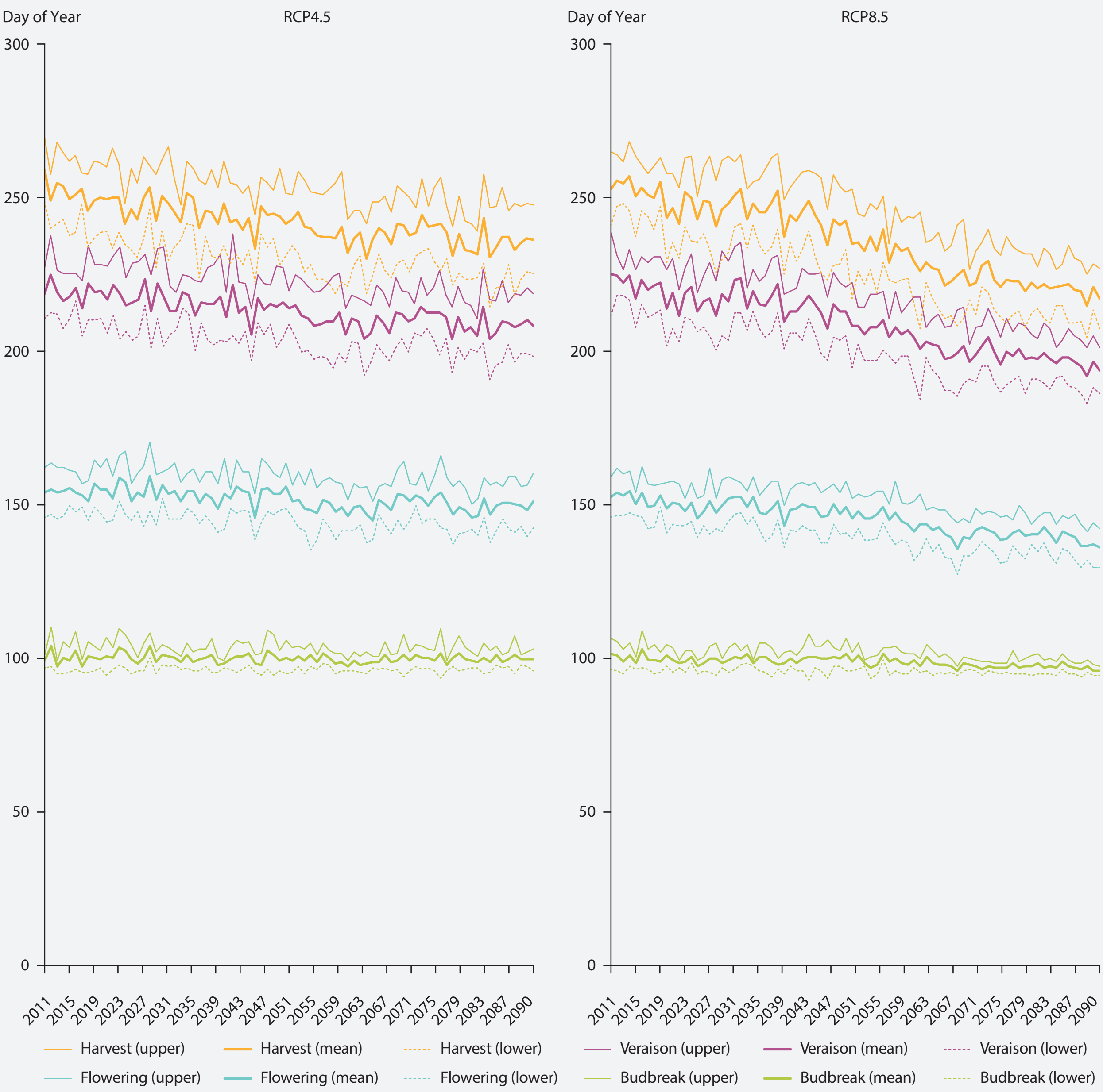
Source: Copernicus Climate Change Service AgriCLASS project.

([33]) http://visca.eu/index.php

Box 4.8 Climate impacts on grapevine phenology

In the framework of the AgriCLASS Copernicus C3S project, a study was conducted in southern France to highlight the effect of changing temperatures in four phenological stages of vines: budbreak, flowering, veraison and maturity. The growing degree days, i.e. the integration of temperature over time, was used as a bioclimatic indicator for vine development. Changes in this indicator directly affect vine phenology, with consequences for wine quality, taste and yield. The development dates and phenological stages of local grape varieties were investigated through a combination of historically observed bioclimatic indicators and crop phenological indices. The primary effect of climate change on phenology is a shift in harvest date of 3-4 weeks earlier. This will affect wine quality by reducing the sugar content. Projections of these crop indicators with three climate scenarios (RCPs 2.6, 4.5 and 8.5) were produced to inform wine growers about the effects of future climate on wine quantity and quality and to support them in optimising management practices and choosing the most appropriate grape varieties (Figure 4.3).

Figure 4.3 Projected phenological stages of vine under two emission scenarios



Note: Four different phenological stages are presented. Mean Day of Year (DOY) is presented as ensemble mean based on different regional climate models for southern France. Mean values and lower and upper limits based on several models are presented.

Source: Copernicus Climate Change Service AgriCLASS project

Box 4.9 Water footprint of arable crops across Europe

Water is a precious resource, especially in drought-prone regions. Climate projections for Europe indicate increased drought conditions in southern Europe and prolonged dry spells in central Europe. Future water demand will also be increased by the rising population, in addition to the agriculture and energy sectors (i.e. the water-food-energy nexus). A study conducted over 45 locations across Europe (Gobin et al., 2017) (Map 4.12) investigated the dependence on water footprints (WFs) used for arable crop production by crop yield, season, irrigation method and region. The crop water footprint reflects water use per harvested crop and considers three major sources of water: water from rain (green WF) and from irrigation (blue WF) and water for diluting chemicals (grey WF). Each component was estimated for various arable crops, both rainfed and irrigated. The study revealed that the WF variability of arable crops across Europe is mainly due to variability in crop yield and, to a lesser extent, variability in crop water use. The WF of cereals is larger than the WF of tuber and root crops, owing mainly to the difference in yield and moisture content between these crop types at harvest. The study also revealed that water-saving irrigation and soil conservation techniques could help reduce the WF. A knowledge of WF variability will be crucial for good water governance in future, particularly under climate change conditions. It helps estimate crop water consumption, thus contributing to more efficient agricultural water management and governance within the framework of the water-food-energy nexus.

Map 4.12 Sites of investigated Water Footprint calculation across European regions

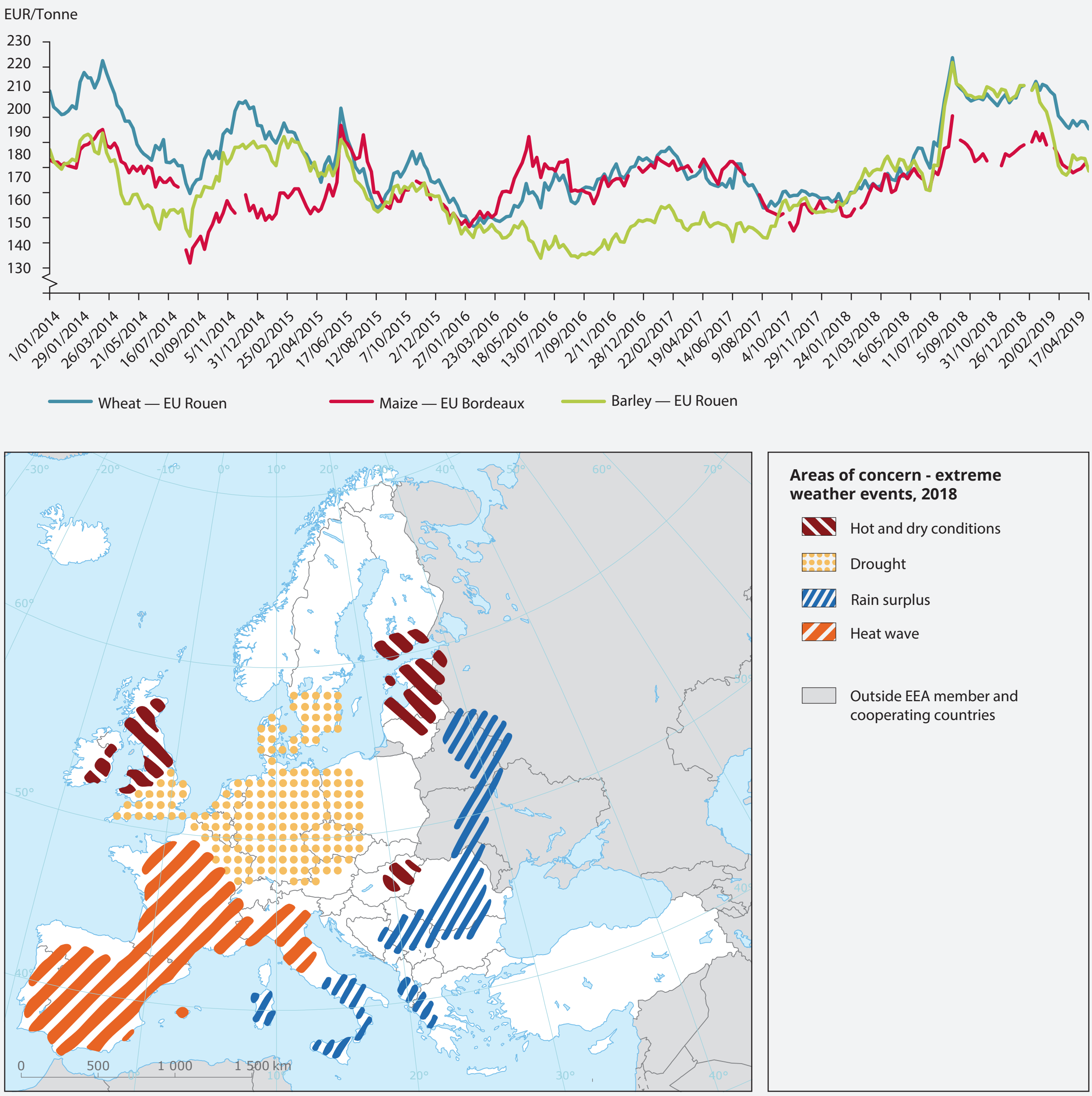
Note: 45 different sites were selected, across the agricultural regions in central, eastern and northern Europe.

Source: Gobin et al. (2017).

Box 4.10 The impact of extreme weather events on commodity prices in 2018

Extreme weather events (rain surplus, drought, heat waves, and cold spell), in addition to changes in the mean of climate parameters, are expected to affect the price of agriculture commodities. For example, in 2018 extreme weather and climate events (mostly drought conditions in central Europe) impacted yields and generated an upward trend in prices of cereals in the EU, with jump in prices in the summer 2018 (Figure 4.4).

Figure 4.4 Cereal prices in the EU between January 2014 and April 2019 for wheat, maize and barley (top) and area of concern with 2018 extreme weather and climate events (bottom)



Note: Extreme weather events in Europe from July to September 2018 affecting the price of commodities in 2018 include heat waves and drought conditions.

Source: EU Crops Market Observatory (Directorate-General for Agriculture and Rural Development (DG AGRI)) and JRC MARS bulletin (2018).

5 Responses to climate change: increasing the adaptive capacity of the agriculture sector

Key messages

- A range of programmes at global and EU levels offer opportunities to finance adaptation measures. The common agricultural policy provides a financial framework for financing adaptation at regional and farm levels.
- There are a number of adaptation measures available at various spatial scales for adapting crop, livestock, viniculture and horticulture production to climate change, with various benefits for mitigation, soil quality and biodiversity.
- Many adaptation measures at the farm level are largely extensions of existing climate risk management or measure to enhance production in response to a potential change in the climate risk profile. In the future, the need for risk management tools will probably increase because of the greater frequency and magnitude of extreme events.
- An opportunity to streamline climate change adaptation in the farming sector is presented through the farm advisory system. Such systems are mandatory under the common agricultural policy, and whether to include adaptation information as mandatory content should be considered.

5.1 Introduction

The adverse effects of climate change can be contained through policies on water and land use, capital investments aimed at reducing economic losses, international trade with regions that are positively impacted and farm-level adaptation. The policy framework on adaptation to climate change at global and EU levels was outlined in Chapter 2. The policy framework is in place to support adaptation within the agriculture sector. However, the policies may still support maladaptation (e.g. irrigation without farm-level water-saving requirements), and there are still practical problems in implementing the adaptation measures at various geographical scales and governance levels.

This chapter provides an overview of the potential solutions offered by policies at various governance levels for adapting to climate change, namely through programmes and by introducing adaptation measures at farm level. While policies are the drivers that set the objectives for action, programmes that derive from these policies offer more concrete support for implementing measures on the ground (Figure 5.1). Global-, EU-, national- and regional-level programmes provide a framework for action at farm level. Depending on the programme, they can provide knowledge (Copernicus Earth observation programme ([34]), Horizon 2020 programme ([35]), LIFE+ programme ([36])), capacity support (Food and Agriculture Organization of the United Nations adaptation programme (FAO-Adapt)) , financial support and suggestions for measures (at EU and national/regional levels). In some cases, they also provide a political mandate for implementing measures.

There are opportunities for introducing efficient adaptation measures applicable to various European regions, and various policies and tools foster their implementation. At farm level, the measures included in this report can be grouped based on the different farm practices, such as arable crop production, livestock, viticulture and horticulture, and on the climate change impacts addressed. The farm-level measures are supported by measures at national and regional levels, such as early warning systems, risk management, education and awareness raising.

In addition, when the impacts of weather and climate events affect countries that are insufficiently prepared to face the adverse effects and technological advances and changes in economic policies may be too costly or cannot take place in time, international trade can

([34]) https://www.copernicus.eu/en
([35]) https://ec.europa.eu/programmes/horizon2020
([36]) https://ec.europa.eu/easme/en/life

play a valuable role in helping such countries to adapt to the extremes (Stevanović et al., 2016; Tamiotti et al., 2009). In the long term — from a climate change perspective — international trade could also contribute towards adjusting agricultural production in an efficient manner across countries (FAO, 2018b). Nevertheless, the extent to which international trade can act as a buffer depends on how economic scarcity or abundance translates into price changes across markets. An orientation towards trade liberalisation, if regulated and compatible with the environment, climate and sustainability objectives, could facilitate the introduction of adaptation (see Chapter 2).

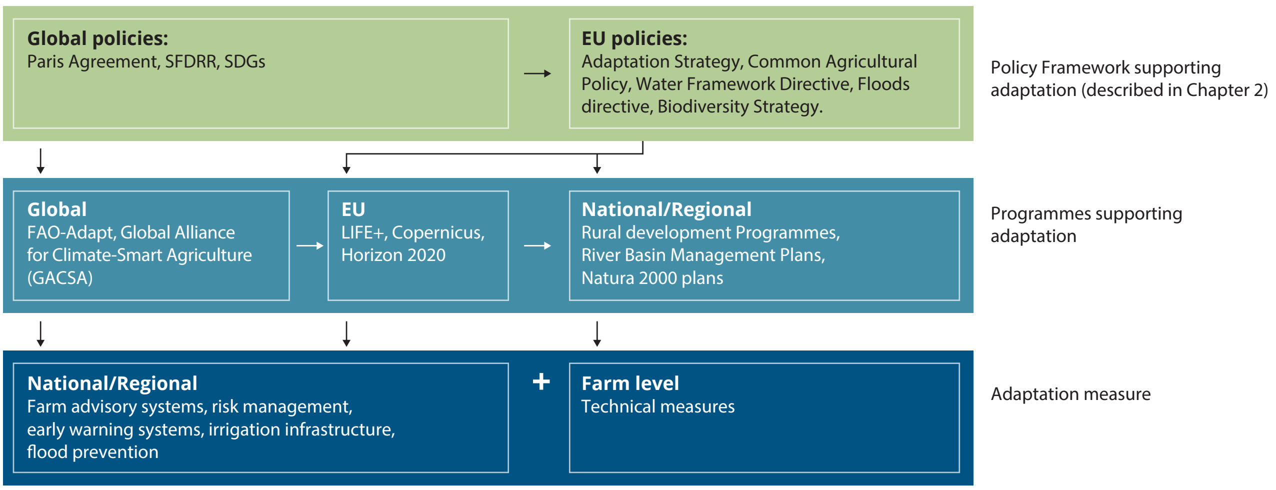
5.2 Selected programmes that support adaptation in agriculture at global and EU levels

5.2.1 Global level

The FAO provides indicators to measure the distances to the targets for achieving the Sustainable Development Goals and agreed targets to reduce the risk of disasters in the global agriculture sector. Between 2011 and 2016, the FAO established FAO-Adapt (FAO, 2011) as a response to the global call for measures to tackle climate change through adaptation. As a framework programme for climate change adaptation, FAO-Adapt promoted activities in agriculture, forestry and fisheries that can lead to sustainable production increases while promoting resilience to the current and future impacts of climate change. There were different priorities for different regions of the world. The priorities for Europe were:

- Assess and monitor the impacts of climate change on agriculture sectors and conduct climate change vulnerability assessments.
- Communicate information and promote equitable access to information related to impacts of climate variability and climate change.
- Establish a climate change data management system.
- Strengthen institutional capacities and coordination for adaptation and access to financial resources.
- Breed and conserve crops, trees, livestock and fish that are adapted to changing climate conditions.
- Establish an interface between climate change, agriculture and rural development.

Figure 5.1 Interaction between policies, programmes and measures at various geographical scales and governance levels



Note: Policies at global and EU levels and that influence programmes at global, EU and national/regional levels, which drive the implementation of measures at national/regional and farm levels.

SFDRR, Sendai Framework for Disaster Risk Reduction.

SDGs, Sustainable Development Goals.

Source: EEA.

- Fully involve ministries of agriculture in the work on adaptation and mitigation and on national communications reports to the United Nations Framework Convention on Climate Change (UNFCCC), incorporating climate change-related policies into rural development and agriculture.

- Disseminate policies on good agriculture practices for adaptation to climate change impacts and their mitigation, based on solid scientific foundations, for sustainable management of land and water and protection of biodiversity.

Within the FAO's sustainable land use theme, the climate-smart agricultural (CSA) programme focuses on expanding the evidence base on the vulnerability of the agriculture sector within the context of food security; supporting enabling policy frameworks; strengthening national and local institutions; enhancing financing options and implementing practices at field level. The Global Alliance for Climate-Smart Agriculture (GACSA) is a multi-stakeholder platform, of which various EU Member States and European institutions are members. GASCA focuses on knowledge sharing and improving the effectiveness of investments and promotes the integration of climate-smart agriculture into policy.

5.2.2 EU level

The EU funds a broad range of research and development activities under its main funding lines, such as Horizon 2020, LIFE+, Interreg and the Copernicus programme.

Innovation and knowledge largely contribute to a more sustainable agriculture sector. From robots to satellites, technology and innovation is slowly changing agriculture. A large amount of information is now accessible to a broad population, not only allowing farmers greater precision in their daily activities but also helping improve the quality of weather forecasts, crop monitoring and predicting yields. This combination allows not only local responses, such as more responsible use of resources, but also responses at European level, to inform decision-making and policy shaping (EC, 2018b). The following actions exist:

- LIFE Climate Action is an EU programme dedicated to developing innovative responses to the challenges of climate change across the EU. It supports the implementation of the strategic priorities of EU climate policy within the EU and is therefore an important element of the overall mainstreaming of climate action within the EU budget. So far, several projects dealing with adaptation in the agriculture sector have been funded, including LIFE AGRI ADAPT ([37]).

- Horizon 2020 is an EU research programme that finances multi-year research and innovation projects. At least 60 % of the total Horizon 2020 budget will be related to sustainable development, with the vast majority of this expenditure contributing to mutually reinforcing climate and environmental objectives. An example of such a research project in the area discussed is the MOSES project ([38]). The main objective of MOSES is to put in place and demonstrate, at a real scale of application, an information platform devoted to water procurement and management agencies (e.g. reclamation consortia, irrigation districts) to facilitate planning of irrigation water resources.

- The ERA-NET instrument ([39]) under Horizon 2020 is designed to support public-public partnerships in their preparation, establishment of networking structures, design, implementation and coordination of joint activities, as well as topping up of single joint calls and actions of a transnational nature. Aspects of agriculture and climate change have been addressed in the European Research Area Network on Sustainable Animal Production (ERA-NET SusAn) ([40]), which intends to pool funds for a transnational call for research projects.

- Joint Programming Initiative Climate is directed at building the European Research Area Networks through enhanced cooperation and coordination of national research programmes in participating EU Member States and associated countries. The European Research Area for Climate Services (ERA4CS) has selected 26 projects on climate services, and many of them (e.g. Climalert, WATExR and Clisweln) have been directly or indirectly addressing the agriculture sector through improving data, models and scenarios.

([37]) http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=search.dspPage&n_proj_id=5661
([38]) http://moses-project.eu/moses_website
([39]) The ERA-NET under Horizon 2020 merges the former ERA-NET and ERA-NET Plus into a single instrument, with the central and compulsory element of implementing one substantial call with top-up funding from the Commission.
([40]) http://www.era-susan.eu

- Climate-KIC is a public-private innovation partnership focused on climate change — and also includes adaptation issues. Climate-KIC is one of three knowledge and innovation communities created in 2010 by the European Institute of Innovation and Technology. One of the Climate-KIC's four themes is sustainable land use, which includes adaptation activities within the agriculture sector. The CSA Booster brings together researchers, practitioners and experts to accelerate technologies and approaches that reduce greenhouse gas (GHG) emissions and support adaptation while enhancing yields. Its mission is to accelerate the climate-smart approach to agriculture, developing and promoting CSA technologies across Europe and beyond. CSA Booster operates in five test regions in France, Italy, the Netherlands, Switzerland and the United Kingdom.

- The European Innovation Partnership for Agricultural Productivity and Sustainability (EIP-AGRI) was launched to contribute to the EU's Europe 2020 strategy for smart, sustainable and inclusive growth. The EIP-AGRI works to foster competitive and sustainable farming and forestry that 'achieve more and better from less'. It contributes to ensuring a steady supply of food, feed and biomaterials, developing its work in harmony with the essential natural resources on which farming and forestry depend. Multiple focus groups ([41]) within EIP-AGRI focus on climate change mitigation and adaptation, for example the Focus Group on water and agriculture ([42]) and the Focus Group on diseases and pests in viticulture ([43]).

- The European Innovation Partnership on Water (EIP Water) facilitates the development of innovative solutions for addressing major European and global water challenges. The EIP Water aims to remove barriers by advancing and leveraging existing solutions. Its implementation started in May 2013, with the main objective of initiating and promoting collaborative processes for change and innovation in the water sector across the public and private sectors, non-governmental organisations and the general public.

- Copernicus is the EU's Earth observation programme, looking at our planet and its environment for the ultimate benefit of all European citizens. It offers information services based on satellite Earth observation and in situ data (e.g. from ground-based weather stations, ocean buoys and air quality monitoring networks) ([44]). The programme is coordinated and managed by the European Commission. It is implemented in partnership with Member States, the European Space Agency, the European Organization for the Exploitation of Meteorological Satellites, the European Centre for Medium-Range Weather Forecasts, EU agencies (including the EEA) and Mercator Océan. Copernicus offers a set of services, one of which is the climate change service and several applications relevant for the agriculture sector.

Implementation of the adaptation measures at national, regional and farm levels is also supported by the rural development programmes (RDPs). The RDPs are funded by the European Agriculture Fund for Rural Development (EAFRD), which receives about 20 % of the overall common agricultural policy (CAP) budget. The main strength of the RDPs in promoting adaptation to climate change in Member States is that the EU provides co-financing (rates vary depending on the measure) for the measures, thus supporting the Member States and regions in their adaptation efforts.

Such measures include knowledge and awareness/farm advice, farm modernisation (e.g. irrigation efficiency programmes), measures to combat adverse effects of weather events, which includes droughts and floods, risk management tools such as insurance, agri-environment-climate measures on adaptation and organic farming.

In addition to the RDPs, programmes/plans under EU environmental policies provide political motivation and a mandate for Member States to offer measures at regional and farm levels to adapt to climate change, namely the river basin management plans under the Water Framework Directive (WFD), and the flood risk management plans (FRMPs) under the Floods Directive and Natura 2000.

5.3 Adaptation measures

In agriculture, adaptation measures occur on a variety of spatial scales, including at national, regional and farm levels. At the same time, responsibility can be

([41]) For a full list of the Focus Groups and access to their reports, see https://ec.europa.eu/eip/agriculture/en/focus-groups/diseases-and-pests-viticulture

([42]) For more information on the outputs of the Focus Group on water and agriculture, see https://ec.europa.eu/eip/agriculture/en/focus-groups/water-agriculture-adaptive-strategies-farm-level

([43]) For more information on the outcome of the group's assessment on increasing the resilience of grape vines to pests, see https://ec.europa.eu/eip/agriculture/en/focus-groups/diseases-and-pests-viticulture

([44]) http://www.copernicus.eu

differentiated among the various stakeholders that undertake or facilitate adaptations in agriculture, including individual farmers, private industries and governments (Smit and Skinner, 2002).

Adaptation measures in the agriculture sector can be implemented at the national/regional level through, for example, early warning systems and risk management schemes that require collective action and can be implemented at farm level — usually technical measures — to address specific issues. This section provides an overview of a selection of measures (non-exhaustive) at national, regional and farm levels that can be implemented to adapt the sector to various climate change pressures. The measures at farm level are grouped according to production type (Figure 5.2).

5.3.1 National and regional levels

Some measures for adaptation to climate change need to be implemented at national and regional levels to take advantage of landscape scale or to address many farmers. Measures at national/regional level include measures for awareness raising and advice (i.e. farm advice), risk management, irrigation infrastructure and flood prevention.

Awareness raising and advice

Farmers in the EU are already experiencing climate change and are aware of the growing impacts (Sima et al., 2015; Pedersen and Nielsen, 2014; Lorecova et al., 2014). While awareness among farmers has

Box 5.1 Climate change adaptation in farm advice

In England ([45]), the 'farming futures' website has been developed through the collaboration of a number of farmer organisations and Defra (the government's agriculture and environment department), which provides easily accessible information on opportunities and challenges related to climate change to farmers, land managers and their advisors and influencers, to drive on-farm climate change adaptation and mitigation. The series of 25 fact sheets that have been produced to date provides information on available funding opportunities that land managers may be able to take advantage of.

Source: EC (2013a).

Figure 5.2 Selection of adaptation measures at national, regional and farm levels

National/Regional level

- Integrating adaptation into farm advice
- Risk management insurance against weather and climate
- Improving efficiency of irrigation infrastructure
- Flood management and prevention

Farm level:

- Arable cropping
- Livestock farming
- Viniculture
- Horticulture

- Ecosystem compatible drainage
- Improve irrigation efficiency
- Precision farming
- HNV or organic farming
- Modification of crop calendars
- Cover crops
- Use of adapted crops
- Field margins
- No tillage or minimum tillage
- Crop diversification and rotation
- Breeding livestock for greater tolerance and productivity
- Improve pasture and grazing management
- Improve animal rearing conditions
- Prevention of climate change induced diseases for livestock
- Modifying fertilization and spraying applications
- Installation of greenhouses
- Protection and monitoring equipment
- Farm activity diversification

Notes: The figure illustrates the different adaptation measures that can be implemented in the agriculture sector.
HNV, high nature value.

Source: EEA.

([45]) This measure is offered only in England and not in other parts of the United Kingdom. Farm advice is governed separately in each region.

increased significantly over the years, advice on which measures to implement for better adaptation at farm level is still needed. The farm advisory system (FAS) under the CAP reaches a wide audience and therefore offers a big opportunity to provide climate change adaptation advice to the farming sector (Box 5.1). Offering and financing the FAS is obligatory under the CAP, with the aim of helping farmers better understand and meet the EU rules for environment, public and animal health, animal welfare and good agricultural and environmental conditions. The scheme allows farmers to implement solutions appropriate for their specific situations, including aspects of climate change adaptation, even if not mandatory. Although the integration of climate change adaptation into the FAS was encouraged by the Commission in its 2014 guidance on integrating adaptation in the RDPs, this has not taken place. Despite not being mandatory, there are examples of adaptation being included in farm advice modules.

Risk management

Farmers are exposed to different types of risks that influence agricultural activities, including price risks, production risks, diseases and extreme weather, and income risks (EC, 2017g). In general, three types of risk management schemes can be distinguished (EC, 2017g; JRC, 2006; EP, 2016):

- Calamities funds are regulated by governments and are provided on a regular (yearly) basis. The main advantage of the funds over ad hoc aid is that they avoid big distortions of the government's budget. Funds sometimes also receive contributions from the private sector, usually in the form of compulsory levies on production or levies on premiums (Box 5.2).

- Mutual funds are owned by the participants. If mutual funds are organised regionally, the advantage is that farmers organise their own cross-control, reducing moral hazard and adverse selection. The disadvantage of regionally organised mutual funds is the danger that many or even all farmers may incur losses at the same time. When farmers are not sufficiently organised to set up an efficient mutual fund structure, the options include re-insurance or cooperation with mutual schemes in other regions.

- Private insurance as a risk-pooling tool: In most EU Member States, agricultural producers purchase crop/yield insurance to protect themselves against the loss of their crops as a result of natural disasters (mainly hail, drought and floods). Insurance schemes in the livestock sector are generally less well developed than in the crop sector, focusing mainly on accidents and non-epidemic diseases. Livestock risk management relies on sanitary assistance programmes; major crises (diseases with high externalities) are covered by public aid (Bielza Diaz-Caneja et al., 2009).

Currently, agricultural insurance mainly focuses on hail insurance, with multi-peril insurance available in a few Member States. Premiums for agricultural insurance are quite high, which is why many countries subsidise such insurance (Ramboll Environment and IVM, 2017).

Box 5.2 Risk management financing under the RDPs

The tools for risk management in agriculture are distinguished in strategies concerning on-farm measures (diversification of production programmes) or risk-sharing strategies, such as marketing contracts, production contracts, hedging on futures markets or participation in mutual funds and insurances. The EU Rural Development Regulation offers co-financing to Member States for the following risk management tools:

1. For the period 2014-2020, under the EU RDPs, Member States or European regions can support farmers in buying insurance, under the condition that the losses covered represent more than 30 % of the farmer's average annual production, based on a 3-year average or an 'Olympic' average (i.e. average over the last 5 years, excluding the highest and lowest value.

2. Financial contribution to mutual funds can be co-financed in relation to climatic risks. Costs covered include administrative costs of setting up the fund and financial compensations to farms.

3. The income stabilisation tool (IST) is a mutual fund that compensates for income losses. Co-financing from the EU is similar, as with other mutual funds.

Source: EC (2017g).

If insurance schemes are to be an effective climate risk management tool for the agriculture sector, a recent study (Ramboll Environment and IVM, 2017) on the performance of insurance against weather and climate-related disaster risk recommends the following:

- As the agriculture sector is and will continue to be affected by multiple climate change, premium subsidies should offer multi-peril (yield) crop insurance products to provide more extensive coverage. Each extreme weather event can contribute to the overall premium, in line with its risk level.

- To reduce the presence of adverse selection in crop insurance and only insuring high-risk land, a farmer should be compelled to insure all arable land as part of the terms and conditions of an insurance policy. This could reduce the overall costs by spreading the risk. It also helps protect against future risk on land currently not affected by climate change but that may be further down the line.

- Link access to wider agriculture sector subsidies (i.e. those relating to the CAP or those offered at national level) to the purchase of sufficient insurance protection to develop a culture of being insured. Increasing subsidies for insurance policies will incentivise more farmers to purchase insurance.

- Support the use of farm income insurance by starting pilot initiatives in various Member States (see Box 5.3).

Box 5.3 Agricultural insurance, Austria

The indemnity-based yield insurance in Austria includes an option for index-based products against certain conditions, such as a reduction in rainfall, rather than actual yield loss. Index-based insurance pays compensation if, for example, rainfall deviates from a pre-specified level. Farmers can voluntarily insure crops against a list of risks by means of an indemnity-based yield insurance known as AGRAR Universal. Policy holders are obliged to insure the entire production for each insured crop. Drought insurance is available for all cereal crops (including maize), potatoes, pumpkins for seed oil production, soybeans, sunflowers and peas. Grassland, sugar beet, vineyards and fruit crops cannot currently be insured against drought.

The insurance covers damages if both of the following conditions are fulfilled:

1. The precipitation during the vegetation period is less than 90 % of the average precipitation during the last 10 years, or the precipitation on 30 consecutive days is less than 10 mm.

2. Yields per hectare are below the defined threshold value.

Premium subsidies for agricultural insurance are financed by a disaster fund (Katastrophenfonds). Compensation payments from the fund are matched by provincial governments, as is reflected in the law on subsidies for hail insurance. In response to the 2013 and 2015 droughts, and the extensive frost damage in spring of 2016, the Austrian government amended the law again, requiring that the existing subsidies for hail and frost insurance be extended to additional weather extremes such as drought, excessive rainfall and storm.

Source: IIASA (2017).

Box 5.4 Flood meadows in the Marais Poitevin, France

Located in the regions Pays de la Loire and Poitou-Charentes, the Marais Poitevin is the second largest wetland in France. About 2 000 ha of flood meadows are owned by local municipalities and commonly managed by local farmers. The meadows are used to retain water during flood events, and water is stored there throughout the winter. To combat the trend of farmers abandoning these meadows, management agreements between municipalities, the Parc Interrégional du Marais Poitevin and environmental non-governmental organisations, as well as agreements between municipalities and farmers, have been signed to ensure that the meadows are used for extensive grazing. Farmers receive financing through the CAP to use the meadows extensively.

Source NRWM (2013).

While insurance schemes have the potential to disincentivise the implementation of technical adaptation measures at farm level — the idea being that farmers with insurance do not take action, as crop losses are covered — the design of insurance schemes can counter-balance this theory. If premiums are tied to the level of claims of previous years, farmers would be incentivised to implement adaptation measures to reduce negative effects on their farms to avoid paying higher premiums in the following years, that is, the lower the claims the lower the premiums (Ramboll Environment and IVM, 2017).

Irrigation infrastructure

Irrigation practices in large areas of southern Europe continue to rely on gravity-fed surface irrigation, as opposed to pressurised irrigation systems: 51 % in Catalonia, 70 % in northern Italy and 63 % in Portugal (Masseroni et al., 2017). In such systems, the water is conveyed from surface water and is distributed to individual fields through canals. In some cases, pumps may also be used to move water from the original source to the application field; thereafter, the fields are irrigated through gravity. Most irrigation systems rely on a network of open channels, but pipes are also used if the application technology requires a pressurised system (e.g. for drip irrigation). In some regions, such irrigation infrastructure is managed by the local region or shared by a collective. By improving the control of flow in the irrigation canals (district scale), the efficiency of these conveyance systems can be increased (EIP-AGRI, 2016). At the regional or district scale, water distribution is not usually metered.

Improvement measures related to the conveyance system include (Bio Intelligence Service et al., 2012; Masseroni et al., 2017):

- improved canal conveyance efficiency through lining open channels, which can reduce water losses (water seeping into the soil) by around 60-80 %;
- replacing open canals with low-pressure piping systems to reduce losses due to evaporation and seepage;
- metering to increase awareness of water use and ensure that water use is properly accounted for and paid for, as required by the EU WFD; and
- automation and remote control of gravity — a key success factor for modernisation is education and training (e.g. as subsidised under the CAP).

Flood management

Flood risk management, which is governed by the Floods Directive and the Flood Risk Management Plans, is implemented at the regional level, although the impacts of such measures can be felt at farm level.

Measures to reduce flooding impacts on farms and boost their resilience against increasing flood events include:

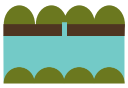
- restoration and new construction of polders or floodplains near agricultural fields (Box 5.4);
- adapting guidelines at regional level for technical infrastructure, such as dykes, to consider the frequency and intensity of flood events in the light of future climate change;
- afforesting abandoned land and of certain agricultural areas to protect productive areas;
- maintaining river beds to ensure retention capacity to avoid flooding of nearby agricultural fields;
- undertaking cooperation measures with farmers to use fields as natural retention areas.

5.3.2 Technical measures at farm level

Adaptation at farm level focuses on technical measures that change production patterns, methods, farm structures and strategies. Technical measures relate to changes in agricultural practices as a result of rising temperatures, for example drought-resistant crops, responsible and targeted use of pesticides, sustainable water use, depending on the local circumstances, use of hail and frost protection, flood prevention, etc.

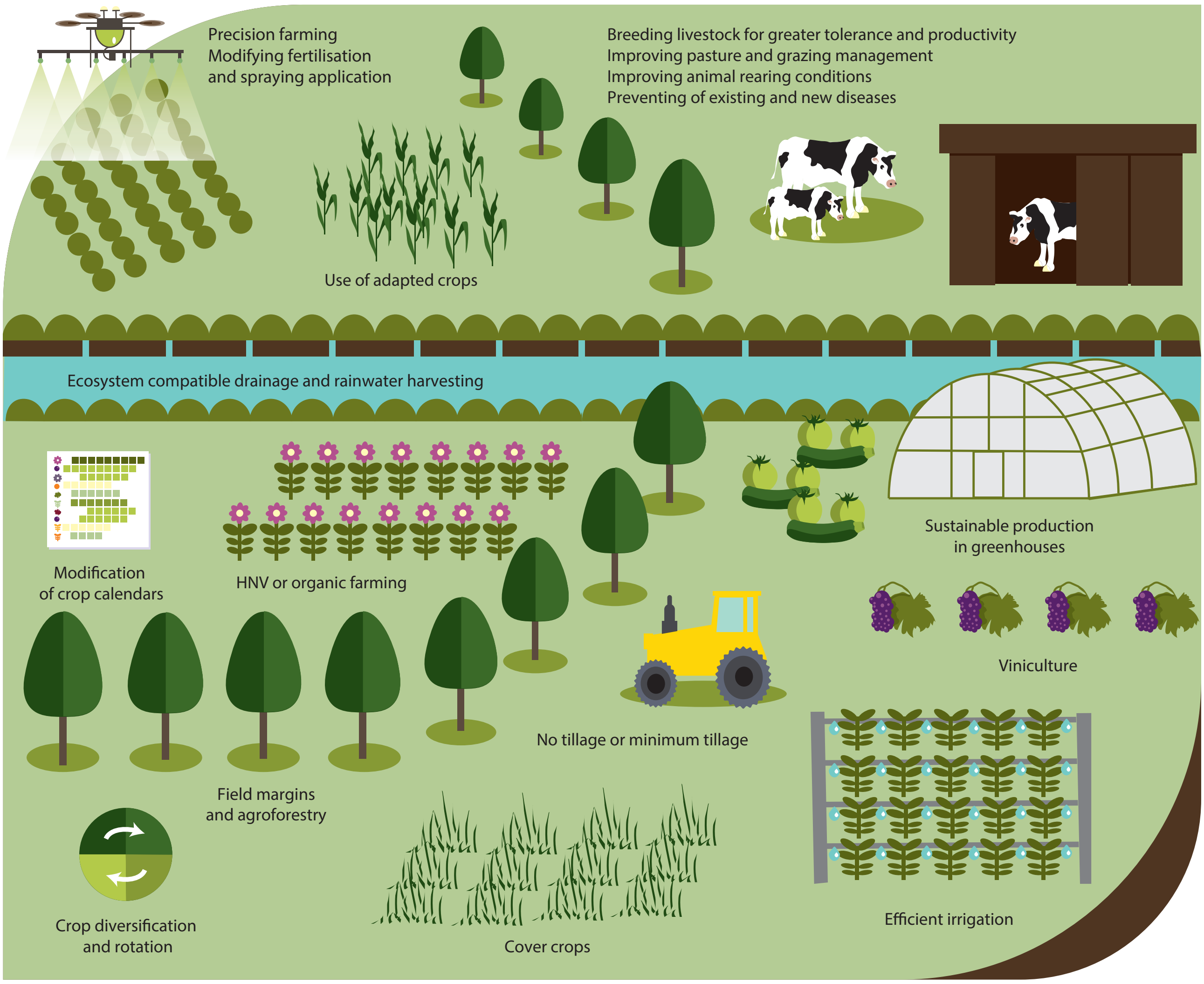
Farm-level adaptation should address the specific needs of farms. The adaptation needs depend on the specific climate impact, the economic situation of the farm, the size of the farm and the cultural background and education of the farmer. These measures aim to enable better management of soils and water, which can provide co-benefits, helping adaptation, mitigation and other environmental objectives and are also economical. The objectives of these measures are to sustain resilient production, conserve soil and water resources, and reduce droughts, pests and other climate threats, as well as reducing emissions or sequestering carbon.

Each farm-level measure corresponds to different climate change impacts and can be relevant for different production types (i.e. arable cropping, livestock farming, horticulture and viniculture). The summary of each measure briefly describes how the measure adapts to climate impacts, the mitigation co-benefits, and impacts on biodiversity and ecosystems (Figure 5.3).



Ensuring ecosystem compatible drainage of agricultural land will help to reduce the impacts of floods on fields, reduce waterlogging, increase infiltration and reduce runoff (and hence erosion), and improve soil structure or promote contour ploughing (Cárcamo et al., 1994; Posthumus et al., 2015; Smith et al., 2014a; Eagle et al., 2012). **Mitigation effects:** optimised drainage decreases soil compaction and erosion, and therefore loss of carbon, and nitrogen runoff leaching. It contributes to lower nitrous oxide (N_2O) emissions in well-drained crops. **Impacts on biodiversity and ecosystem services:** it is essential that drainage systems are designed in a way that avoids negative impacts on water-dependent ecosystems. Modifying existing drainage systems can help to ensure the correct water levels needed for agricultural crop production while enabling more natural water flow during times when drainage is not needed as much (RSPB, 2010). Such modifications can improve surface and sub-surface water flows, ensure water levels needed for wetlands, and maintain soil drainage. The design of any drainage measures needs to consider potential negative implications for water quality if drained water (which can contain nutrients from fertilisers and pesticides) is allowed to directly discharge into water bodies. Costs including

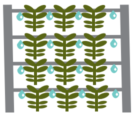
Figure 5.3 Measures at farm level



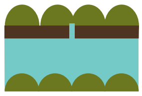
Note: Figure presents selected adaptation measures and their placement in the farm areas.

Source: EEA.

construction and maintenance may outweigh the short-term benefits when viewed from a farm financial perspective.



Improved irrigation efficiency: significantly reduces water use; however, modification of existing systems and installation of new technologies for more efficient irrigation may involve high capital and maintenance costs (see Box 5.5) (Eagle et al., 2012; Smith et al., 2007). It is important to ensure that irrigation efficiency gains at farm level lead to effective water savings and do not result in an expansion of irrigation areas and thus no water savings or even increased water use. **Mitigation effects:** improved irrigation efficiency can enhance carbon storage in soils through enhanced yields and crop residues. Drip and buried tape (versus surface) irrigation reduces N_2O fluxes, although annual mitigation effects cannot be determined. **Impacts on biodiversity and ecosystem services:** more efficient irrigation would lead to less abstraction and can significantly reduce pressures on both surface and groundwater systems. This, in turn, could have favourable impacts on water ecosystem services, in terms of both supply and quality, and on soil ecosystems and soil biodiversity. Furthermore, lower water use means that more water becomes available for a longer period, helping to ensure long-term security of food provisioning services. Adopting soil conservation practices, such as retention of crop residues and mulching, may have some beneficial effects on soil biodiversity particularly in the top soil zone.



Rainwater harvesting: increases the resilience of a farm to water scarcity and droughts (Venkateswarlu and Schanker, 2009). Storage systems require taking

Box 5.5 Improving water retention on an organic farm in Portugal

Herdade do Freixo do Meio is an organic certified farm of 440 ha located in the Alentejo region in the south of Portugal. The region of Alentejo in Portugal is generally classified as an area highly vulnerable to climate change and at high risk of desertification, due to its aridity index and extension of soils with low-quality, combined with the climate scenarios that project, for this region, a decrease in precipitation levels, an increase in the frequency, duration and intensity of droughts and an increase in temperatures. The measures implemented by Herdade do Freixo do Meio aim to reduce its water needs, reduce desertification and soil erosion, and increase resilience to climate change and climate extremes while sustaining an economically viable agro-forestry system.

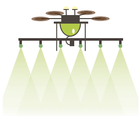
The farm has implemented a wide number of measures aimed at reducing water needs, increasing resilience to droughts, diversifying crop products and increasing awareness of sustainability and climate change adaptation.

Measures to improve water retention and reduce water needs:

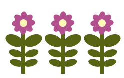
- creation of small dams;
- drip irrigation (to reduce water consumption) with organic fertiliser (farmer made organic liquid fertiliser rich in bacteria which requires training on hygienic handling, introduced in drip irrigation);
- use of renewable energy for water pumping to reduce irrigation costs;
- mulching, i.e. use of straw, leaves, shredded wood, other natural fibres or even compost to cover soil and prevent evaporation;
- tilling on contour lines and no tilling in steep areas, aiming to prevent soil erosion and increase soil water retention;
- keyline design of terrain, trees and crops — this practice increases water infiltration and soil water retention, preventing erosion, increasing pasture productivity and water availability over a larger area, and increasing the depth of roots and the carbon sink;
- increasing soil organic matter to improve soil water retention;
- cultivating the soil with swales and boomerang shapes to increase soil water retention;
- planting trees and crops in areas with particular microclimates within the farm (e.g. north-west slopes have higher levels of humidity).

Source: Climate-ADAPT.

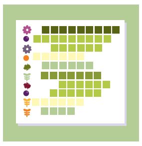
land out of production. The construction and maintenance of rainwater harvesting and storage systems incurs significant costs for farmers (in terms of labour and machinery). **Mitigation effects:** improved rainwater harvesting and storage can result in energy savings. For rain-fed crops, rainwater harvesting increases production per unit of area and inputs. **Impacts on biodiversity and ecosystem services:** the use of rainwater in agricultural production has the potential to lessen the pressures on surface and groundwater abstraction. In contrast, rainwater harvesting could reduce groundwater levels and streamflows, as the water captured will not recharge groundwater levels. It is therefore important to make basin-wide assessments of the impacts of rainwater harvesting as part of proper management of the surrounding ecosystem.



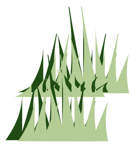
Precision farming encompasses a set of technologies (e.g. global positioning system tools, use of drones) aimed at the management of spatial and temporal variability of the field by optimising yield and input applications, for example fuel, fertilisers, pesticides and water (Balafoutis et al., 2017; Barnes et al., 2019). It can significantly decrease the impacts of weather and climate extremes. This measure may require investment in new machinery, use of information technology (IT) tools and new technologies to use satellite data. It may also increase training and farm management costs (Soto et al., 2019). **Mitigation effects:** significant reductions in GHG emissions can be achieved thanks to a decrease in nitrogen fertiliser application, fertiliser production and fuel consumption (Soto et al., 2019). Precision farming can also enhance the ability of soils and biomass to operate as carbon stock reserves by reducing tillage and increasing yield (Balafoutis et al., 2017), respectively. **Impacts on biodiversity and ecosystem services** are positive because of the reduction in application of inputs. Site-specific and efficient fertiliser and pesticide application might decrease the risk of ground- and surface water contamination (Timmermann et al., 2013). Confining all machinery loads to the smallest possible area of permanent traffic lanes might have a positive effect on soil structure and soil organisms (Balafoutis et al., 2017). Precision weeding can also replace pesticides, preventing the development of pesticide resistance in various weeds.



High nature value (HNV) farmland, with its emphasis on extensive management practices (i.e. low inputs, minimum tillage, low livestock stocking levels and landscape elements), can conserve soils and offers similar benefits, such as reduced tillage, cover crops and improved grazing management. **Mitigation effects:** the reliance on organic fertilisers promotes organic carbon storage in soils. However, more land is required to produce similar outputs, which could lead to higher GHG emissions per kilogram of meat or milk produced. **Impacts on biodiversity and ecosystem services:** HNV farming practices generate high levels of soil organic matter, which enhances water storage capacity and increases resilience to droughts and floods.



Modifying crop calendars can help farmers to take advantage of better early season moisture conditions and a prolonged growing season, and help minimise drought risk periods during grain filling (Yegbemey et al., 2014) (see Box 5.6). Moreover, later planting can also be useful for making more effective use of rainfall and stored soil moisture. The cost of this measure is negligible. **Mitigation effects:** soil carbon storage can be increased thanks to higher yields and large amounts of crop residues when modified crop calendars are used. **Impacts on biodiversity and ecosystem services:** adjusting cultivation timing (or modifying crop calendars) to the new climatic regimes ensures food provisioning services. The changes may have impacts on farms' above-ground biodiversity as well as their soil biodiversity.



Cover crops can significantly reduce the risk of soil degradation, which can be exacerbated by climate change effects, such as an increased risk of intense precipitation and strong wind events, especially during winter (Bergtold et al., 2017; Blanco-Canqui et al., 2015; Delgado et al., 2011; Finney et al., 2016; Gabriel et al., 2013; Posthumus et al., 2015; Smith et al., 2007, 2014a; Tonitto et al., 2006). Cover crops can lead to substantial input cost savings for the following cash crop by adding or recovering nutrients and can generate revenue when sold as biofuel feedstocks. The use of native crop species should be chosen whenever possible (as they are more adapted to local conditions and therefore more resilient). In places where there is no competition for water, the use of green cover with native flora also benefits the infiltration and retention of water and the development of beneficial microbial masses and biodiversity linked to the aesthetic and cultural value of the vineyards. When linked with precision farming, cover crops reduce the need for fertilisation, as well as increasing organic matter in the soil and ensuring less destruction of the structure by compaction and an increase in the microbiome. **Mitigation effects:** the use can reduce N_2O emissions by extracting nitrogen not used by preceding crops and by decreasing nitrate leaching. However, a consideration of carbon and nitrogen

Box 5.6 Adaptation measures in the Romanian Rural Development Programme

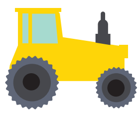
In Romania, the analysis of field crops' output in the last decade — obtained from the network of research units — and the studies based on the use of the agri-soil-climate models for forecasting various crops under various climate scenarios indicate a trend towards lower yields of crops. As a result, during the development of Romanian RDP for the period 2014-2020, measures were selected to achieve the objective 'Climate change adaptation'. The measure package, for which farmers receive financing (EUR 126/ha per year), includes the cultivation of at least two hybrids/varieties, adaptation of the sowing schedule to the modified climate requirements, use of minimum tillage methods and application of livestock manure in composted form.

Risk areas were identified so that the measures could target those areas most at risk. To this end, two data layers were overlapped, namely quantity of water accessible in the soil, calculated from the pedo-transfer function extension of the Romanian soil map 1:200 000, in digital format (SIGSTAR-200), and the number of growing days ,defined as the number of days in a year with an average air temperature above 5 °C, and a ratio between actual and potential evapotranspiration of above 0.5. This indicator was calculated using the Romimpel simulation model for the first case study in 2012 on the set of bio-physical indicators proposed by the Joint Research Centre (JRC) for the designation of areas with constraints for agricultural activities, the SIGSTAR-200 soil database and the climate data for the 1991-2000 time series. The Romanian desertification risk map, indicating the 'critical' areas in which climate change effects on agri-ecosystems could be significant, was drawn up based on specific indicators for the quality of soil, climate and vegetation.

Source: Factsheet on 2014-2020 Rural Development Programme for Romania (EC, 2015c).

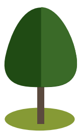
dynamics and balance (input versus output) is needed to better understand the effects on GHG fluxes. Cover crops can improve soil properties (physical, chemical and biological), sequestration of soil organic carbon and nitrogen retention (reduction of nitrate leaching), above-ground biomass nitrogen and nutrient cycling. **Impacts on biodiversity and ecosystem services:** the measure contributes to suppression of weeds, improvement of wildlife habitats and diversity, potential provision of both forage for livestock and feedstock for cellulosic biofuel production, and increased crop yields in regions with abundant precipitation.

Use of adapted crops could reduce the impact of droughts and water scarcity (Delgado et al., 2011; Meehan et al., 2013; Smith et al., 2007). In such cases, shifting to different crops to better attune to the new climate conditions may be the best adaptation option. The cost of implementing this measure is likely to depend on the price of the seed of the adapted crops and whether farmers will need to make large investments as a result of significant structural changes to the farm's production (e.g. a new type of machinery). **Mitigation effects:** soil carbon storage can be increased when adapted varieties of crops lead to higher yields and large amounts of crop residues. Crops with deep root systems (such as maize, wheat, barley) can also accelerate atmospheric carbon sequestration. **Impacts on biodiversity and ecosystem services:** adapted crops are likely to have some effects on biodiversity and ecosystem services. The ultimate effects may also depend on the interactions between the associated practices, such as rotation versus no rotation, diversified versus monoculture, and frequency and length of fallow period. A switch from annual to perennial energy crops can lead to changes in various ecosystem services, including provisioning of producers' income, provisioning of energy, water quality regulation (related to phosphorus loading) below-ground carbon sequestration, annual N_2O emissions, abundance of pollinators and potential for biocontrol.

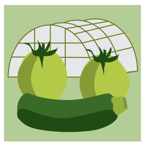


No tillage or minimum tillage induces changes in the soil structure and in the location of soil organic matter and crop residues (Delgado et al., 2011; Kremen and Miles, 2012; Hernanz et al., 1995). This results in changes in biological, chemical and physical soil properties, including soil climate (soil temperature and soil water content). Costs are likely to vary between farms (size and production system/structure), localities and countries. Provided that yields are equivalent, no tillage is more economical than the conventional tillage for large farms (see Box 5.7). **Mitigation effects:** the combination of all these modifications has an important impact on carbon and nitrate transformation in soil and leads to a more intact soil structure. Such soils are more resilient to soil erosion by wind and water. No or minimum tillage increases soil organic carbon and reduces energy consumption by agricultural machinery. Higher N_2O emissions cannot be excluded. **Impacts on biodiversity and ecosystem services:** no or minimum tillage enhances soil drainage and improves food supplies for insects, birds and small mammals, thanks to more availability of crop residues and weed seeds. No or minimum tillage also improves ecosystem services, such as water regulation, carbon storage, soil stability, protection of surface soils from erosion, enhanced water infiltration, increased soil fertility through enhanced nitrogen stocks (in the long term), improved soil, water and air quality, and reduced soil erosion and fuel use. No tillage can lead to an increased need for either pesticides or alternative pest control (e.g. integrated pest control management).

Crop diversification and rotation: spreads the risk of losing an entire year's production, as different crops respond differently to weather and climate (Sanderson et al., 2013; Isbell et al., 2017; Roesch-McNally et al., 2018). A crop system based on a long crop rotation provides more resilience to climate change. Costs are likely to vary, depending on the crops used in rotations and the frequency and length of fallow periods. However, potential loss of revenue, either through rotation or lower value crops or introducing nitrogen-fixing legumes, should be considered within the context of improved soil fertility and reduced fertilisation needs. **Mitigation effects:** crop diversification and rotation generally has little effect on soil carbon but may result in a slight gain. Including a rotation with leguminous crops reduces nitrogen fertiliser needs, field operations and N_2O emissions. Crop diversification and rotation delivers efficient nutrient cycling and soil quality improvement. **Impacts on biodiversity and ecosystem services:** crop diversification and rotation conserve the biodiversity. It also increases water holding capacity in surface soil, improves control of weeds, diseases and arthropod pests, improves pollination services, and reduces erosion and water requirements and nitrogen and other fossil fuel-intensive inputs.



Field margins can slow down the movement of water from soil to watercourses and reduce water and wind erosion (Eagle et al., 2012; Marshall, 2004; Marshall and Moonen, 2002; Meek et al., 2002; Musters et al., 2009; Smith et al., 2007, 2014a; Vickery et al., 2009). Field margins are usually a low-cost solution for reducing the impacts of extreme weather events, as they include only the cost of establishment, and there is no maintenance cost, assuming that shelterbelts are left uncut. **Mitigation effects:** field margins (e.g. shelterbelts and hedges) increase carbon storage through retention of sediment from agricultural runoff and through capture and sequestration in biomass. Field margins can also reduce N_2O emissions by capturing NO_3 before it reaches surface water or groundwater. **Impacts on biodiversity and ecosystem services:** field margins support various fauna, reduce soil erosion, enhance water retention, ensure biodiversity at the landscape level and support farmland birds. The vegetative composition of the field margins should consider both biodiversity and pest control benefits. Field margins are a fundamental element of better incorporating ecosystem management within the agricultural landscape.



Sustainable production in greenhouses combats the likely increase in temperature and water stress periods during the crop growing season (Campiotti et al., 2012; Vourdoubas, 2015). The installation of new buildings and infrastructure for more efficient irrigation technology entails substantial investment and maintenance costs. **Mitigation effects:** sustainable horticulture production in greenhouses would be based on renewable energy sources, that is, geothermal energy at low temperatures, photovoltaic solar energy and solid biomass. In addition, efficiency increases could be achieved with the current technology. **Impacts on biodiversity and ecosystem services:** a closed greenhouse system that captures water could reduce pressures on water ecosystem services, soil ecosystem services and soil biodiversity.

Box 5.7 Reducing tillage in Sweden

The goal of Solmacc, an EU LIFE funded project coordinated by the International Federation of Organic Agricultural Movements (IFOAM) EU group, is to test and share strategies for organic and low-input farming to mitigate and adapt to climate change. The project is scientifically monitoring 12 demonstration farms in Sweden, Germany and Italy. The farmers adjust their agricultural techniques over the course of 5 years, introducing new practices but adapting them to the particular climatic area and farm conditions. Since 2014, the project has been keeping them under close supervision and has maintained a constant exchange between the farmers and their advisors. The farmers are all implementing four innovative, climate-friendly practices, each from four different categories on their farms: (1) optimised on-farm nutrient recycling; (2) optimised crop rotations, (3) optimised tillage system; and (4) agroforestry.

Reduced tillage practices on an organic farm have been shown to reduce costs while maintaining similar yields. On a medium heavy clay soil, farmers have eliminated ploughing in the autumn, sowing cover crops in the winter and sowing directly into the soil in the spring.

Source: SOLMACC project (SOLMACC, 2015).

Measures addressing viniculture include the use of protective and monitoring equipment, such as thermal screening and thermometers, that will allow better temperature control. Investment in thermal screens would provide shade from direct sunlight and prevent mineral deterioration in fruit (see Box 5.8). For adaptation, the systems have been developed to manipulate the temperatures of vines. These include a chamber-free system in which air can be heated or cooled and then blown across grape bunches to get a 10 °C difference in temperature. Mini-chambers combined with shade cloths and reflective foils have also been used to manipulate the temperature and irradiance. By applying polyethylene sleeves to cover cordons and canes and installing hail protection nets led to increases of maximum temperatures by 5-8 °C (for earlier and later growing potential) and decrease minimum temperatures by 1-2 °C (during higher temperatures). Installation of new technology or equipment would require substantial investment and maintenance costs. **Mitigation effects:** healthy vineyards would require fewer inputs and would maintain soil properties (i.e. avoiding erosion and enhancing carbon sequestration); therefore, upstream and in-field emissions would be reduced, in comparison with crops affected by water or heat stress. **Impacts on biodiversity and ecosystem services:** improved fertiliser applications and spraying could reduce pressures on water ecosystem services, soil ecosystem services and soil biodiversity.

Breeding livestock for greater tolerance coupled with improved animal health (see also susceptibility to diseases) can positively impact productivity and reduce grazing pressure on grassland (De Haas et al., 2016; Lee et al., 2004; Lal et al., 2011). More efficient use of grain-based feeds and feeding, through least-cost ration formulation, diversification of species distribution, selective breeding for improved feed conversion efficiency, and incorporation of crop residues and processing by-products, are some of the approaches that can be incorporated into agricultural and livestock projects. **Mitigation effects:** using improved livestock genetics to increase productivity directly reduces the emissions intensity of livestock systems. **Impacts on biodiversity and ecosystem services:** breeding livestock for greater tolerance and productivity to reduce grazing pressure may have beneficial impacts on climate-regulating services (through carbon sequestration), as well as on water and soil ecosystem services and above-ground and soil biodiversity.

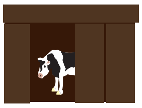
Box 5.8 Adaptation strategy for vineyards in Pulkautal, Austria

The pilot programme 'Climate change adaptation model regions for Austria — KLAR!' is funded by the Climate and Energy Fund and offers a process-oriented approach for regions and municipalities to raise awareness of climate change adaptation and to trigger concrete actions. As part of the pilot project in the Pulkautal region, the following agriculture-related measures are being implemented:

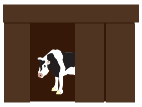
- guided tours of vineyards, focusing on providing information on the impact of climate change on the production of wine in the region; guides are trained on the topic, including the types of measures needed to adapt to climate impacts;
- wine tasting with experts, focusing on existing grape varieties as well as potential new varieties that could grow as a result of the expected climate changes in the region by 2050;
- training of farmers by the university on farm-level adaptation options for viniculture, focusing on soil protection, irrigation, pest control, planting periods and fertilisation, and developing new approaches to tackle impacts;
- a 'show vineyard' planted with existing grape varieties and potential new varieties;
- multi-purpose use of the water retention ponds (for flooding) to combat increasing drought periods;
- rainwater harvesting;
- information days for school children.

Source: KLAR project (2017).

Improving pasture and grazing management can help to reduce soil degradation, wind and water erosion, increase biomass on grassland and improve animal health (Conant et al., 2017; Delgado et al., 2011; Lal et al., 2011). **Mitigation effects:** improved grazing management, fertilisation, sowing legumes and improved grass species and conversion from cultivation all tend to lead to increased soil carbon. Introducing grass species with higher productivity, or carbon allocation to deeper roots and legumes, can accelerate atmospheric carbon sequestration in soils. However, adding nitrogen often stimulates N_2O emissions, and increased irrigation may require more energy. The influence of grazing intensity on emissions of non-CO_2 gases is not well established, apart from effects from adjustments in livestock numbers. Improving pasture quality, especially in less developed regions, improves animal productivity and reduces the proportion of energy lost as methane (CH_4). CH_4 emissions could potentially be reduced by introducing more concentrates in feed, normally replacing forage; animal health implications should be considered when introducing concentrate feed. The net positive or negative benefits will vary depending on site-specific conditions and whether the use of concentrates increases the need for arable land for their production. **Impacts on biodiversity and ecosystem services:** improved pasture and grazing management, including improved grasslands and pastures with reduced grazing pressure, may have beneficial impacts on climate-regulating services (through carbon sequestration), as well as on water and soil ecosystem services and above-ground and soil biodiversity.



Improvement of animal rearing conditions (shading and sprinklers, ventilation systems) improves conditions for livestock production (IPCC, 2006; Gerber et al., 2011, 2013). The investment in and maintenance of new technology for animal housing, such as new cooling systems, can be high; however, the cost of planting trees for shading can be lower and have benefits for biodiversity. **Mitigation effects:** improving animal rearing conditions leads to reduced CH_4 emissions, since emissions decrease with reductions in temperature. In addition, increased animal health and welfare improves the efficiency of feed use and feed intake, which probably leads to lower emissions per unit of production. In particular, in dairy systems, CH_4 and N_2O emissions decrease with increasing productivity, while CO_2 emissions increase but on a smaller scale. **Impacts on biodiversity and ecosystem services:** soil and water ecosystem services and farm biodiversity benefit from improving animal rearing conditions through the indirect effects of planting trees for shading.



Preventing outbreaks of existing or new diseases focuses on addressing livestock diseases induced by climate change, including measures to prevent diseases in animals previously not exposed to certain diseases. Such measures include improving disease surveillance and response, increasing the capacity to forecast climate-sensitive diseases and improving animal health services (CIAT, 2014). Improved surveillance may help to reduce response times, which has the potential to reduce the costs of outbreaks (Grace, 2014). In addition, farmers could focus on breeding species that are naturally more resistant to disease and climate change impacts. **Mitigation effects:** using improved livestock genetics to increase productivity directly reduces the emissions intensity of livestock systems. **Impacts on biodiversity and ecosystem services:** breeding livestock for greater tolerance and productivity to reduce grazing pressure may have beneficial impacts on climate regulating services (through carbon sequestration), as well as on water and soil ecosystem services and above-ground and soil biodiversity.

Diversification of farm income activities can serve as an important farm risk management strategy (Smith et al., 2014a) (Box 5.9). Costs may increase in the case of purchasing new technology for a new activity, such as for animal product processing. Mixed production systems on farms can increase land productivity and efficiency in terms of use of water and other resources, protect against soil erosion and lead to enhanced nutrient use efficiency. **Mitigation effect:** mixed production systems, such as agro-forestry, agro-pastoral and agro-silvo-pastoral systems, double-cropping systems and mixed crop-livestock systems can address carbon sequestration objectives. Numerous studies have measured increases in soil carbon after the application of manure, although carbon storage is not guaranteed. In practice, manure application can, but does not necessarily, lead to full displacement of artificial fertiliser. Integrating feedstock production with conversion, typically producing animal feed, can reduce demand for cultivated feed, such as soybeans and maize, and can also reduce grazing requirements. In addition, agricultural and forestry residues can be used for energy production. **Impacts on biodiversity and ecosystem services:** mixed production systems can increase land productivity and efficiency in the use of water and other resources and protect against soil erosion.

Box 5.9 Common diversification options taken by farmers

Around 12 % of farms in the EU receive income from on-farm diversified activities (Hill and Dylan Bradley, 2015). On-farm diversification is currently primarily driven by the performance of the general economy. The most popular types of diversification activities (i.e. 'other gainful activities') are (Eurostat, 2017b): processing of farm products (22.8 % of farms); contractual work (19 %); other gainful activities not classified elsewhere (16.4 %); and forestry work (15.9 %).

6 The way forward

6.1 Mainstreaming adaptation in EU agricultural policies

Adaptation is already mainstreamed in the current common agricultural policy (CAP) (2014-2020) and is addressed, in particular, under the rural development programmes (RDPs, Pillar 2). The current CAP (2014-2020) still enables coupled payment support, not just for cotton but for additional crops deemed economically important for certain areas. The Omnibus Regulation for 2017-2020 (EU, 2017) enables EU Member States to offer coupled support on the basis of production in a past reference period. Such provisions should be discontinued in the future, as they may prop up production in areas where crop production is no longer viable without such payments because of climate change impacts such as water scarcity, droughts or extreme temperatures. Policy makers in Member States should work with researchers, practitioners and farmers to investigate more suitable production options, given the changing climatic and environmental conditions, and target subsidies for more adaptive production (Frelih-Larsen et al., 2014).

To enhance adaptation in future in the agriculture sector, the European Commission has included four entry points for implementing technical measures at farm level to promote adaptation to climate change in the recent proposal for the CAP 2021-2027: enhanced conditionality (formerly cross-compliance), eco-schemes, sectoral interventions and rural development interventions. This is a sign of further integration of adaptation into the policy framework for the future cycle (2021-2027) compared with the current programming period (2014-2020).

Even with an adaptation-friendly policy framework, adaptation at the farm level does not necessarily take place (Gocht et al., 2017). This is due to a number of factors, including the reliance on voluntary measures (i.e. those that farmers are not obligated to implement), a lack of resources for investment, political urgency to adapt, institutional capacity, and access to adaptation knowledge and information from other countries. Up until now — and in the future programming period — Member States have needed to focus on financing various objectives, and climate change adaptation has been just one priority. With competing environmental objectives, the design of measures offered within the future CAP strategic plans should focus on multi-objective adaptation measures with multiple benefits. Policy makers in Member States should consider adding a provision for payment of ecosystem services tied to adaptation under the eco-schemes to make adaptation measures focused on delivering wider public benefits more attractive to farmers.

Mainstreaming climate action into policies also needs to be done at the national/regional level. While it is positive that adaptation has been elevated to an objective within the CAP, its link to mitigation in terms of target and result indicators to monitor ambition and tracking in terms of expenditure reduces transparency and a clear understanding of efforts at Member State level and below. To ensure that adaptation is adequately included in the national strategic plans, the policy framework should require Member States to offer measures with a focus on adaptation. To this end, Member States should ensure that they include adaptation expertise in the development of the CAP strategic plans. The proposed requirement in the CAP proposal post 2020 to include environmental authorities in drawing up the CAP strategic plans will help to set the basis for inclusion of adaptation.

6.2 Filling the knowledge gaps

6.2.1 *Data and indicators*

The European coverage of data and information on climate change impacts on the agriculture sector is now becoming operationally available through the Copernicus Climate Change Service (C3S) [46]. The C3S offers access to key climate variables and indices through its Climate Data Store [47]. It provides information about the past, present and future climate,

([46]) https://climate.copernicus.eu
([47]) https://cds.climate.copernicus.eu

as well as tools to enable climate change mitigation and adaptation strategies by policymakers and businesses. For the agriculture sector, C3S offers opportunities to increase the resilience of European farming to climate change. Currently, several projects within the C3S are preparing a set of climate variables and indicators tailored for the agriculture sector. Examples are the Global Agriculture Sectoral Information System ([48]) project, which aims to develop global climate services in support of decision-making in agriculture, and the Agricultural Climate Advisory Services (AgriCLASS) project ([49]), which combines climate and agricultural data and models to generate region-specific products for the agriculture sector. These products will provide their users with the information they need to understand how crops are likely to be affected by climate change in the future.

The EEA maintains and regularly updates a set of indicators that provide information on past and projected climate change as well as the observed and projected impacts of climate change on ecosystems, socio-economic sectors and human health. A subset of these indicators provides information on climate change impacts on the agriculture sector. These indicators rely on data from various sources, and in the future the indicators might be more streamlined by using information from the C3S and also by providing direct links with the adaptation measures.

The European Commission has set up a common monitoring and evaluation framework to assess the performance of the CAP and to assess whether the CAP is achieving its objectives. A number of indicator types were defined to monitor the CAP's performance, such as output, results indicator, and impact and context indicators. In the new proposed performance monitoring and evaluation framework, a results indicator has been directly tied to climate change adaptation. In addition, an impact indicator on monitoring farm resilience has also been included. The inclusion of these two specific adaptation indicators is a positive step within the CAP monitoring framework. To ensure proper uptake of information on climate change, its current and future impacts on the agriculture, farm advisory services on adaptation action are essential.

6.2.2 Innovation and knowledge projects

Innovation and knowledge projects largely contribute to a more sustainable agriculture sector. From robots to satellites, technology and innovation is slowly changing agriculture. A large amount of information is now accessible to a broad population, allowing farmers greater precision in their daily activities but also helping improve the quality of weather forecasts, crop monitoring and predicting yields. This combination allows not only local responses, such as a more responsible usage of resources, but also responses at European level to inform decision-making and policy shaping. The EU funds a broad range of research and development activities under its main funding lines, such as Horizon 2020 ([50]), LIFE+ ([51]), Interreg ([52]), Climate-KIC ([53]), the European Innovation Partnerships (in particular the European Innovation Partnership Agricultural Productivity and Sustainability, EIP-AGRI ([54])) and the Copernicus programme ([55]). Better monitoring and evaluation of all the various adaptation approaches under these instruments is essential to further increase the knowledge base on successful adaptation measures in agriculture in Europe. The European Climate Adaptation Platform (Climate-ADAPT) ([56]) is an important tool that supports users to access data and share state-of-the-art and continuously improving knowledge on adaptation, and it enables learning by exchange of good practice between countries.

6.2.3 Understanding better global climate change impacts on European agriculture

Population growth, increasing demand for food and fodder production, changing diets and consumption patterns, biofuel production, and changes in climate conditions are expected to change the agriculture sector globally and in Europe in the coming decades.

There is a need to better understand the complex links between these changes, including climate change impacts on and consequences for trading agricultural commodities. Extreme weather and climate change-related events affecting yields or agricultural policies in non-European countries will also have effects on the EU. Trade may become important to avoid the

([48]) https://climate.copernicus.eu/global-agriculture-project
([49]) https://climate.copernicus.eu/climate-advisory-services-agriculture
([50]) https://ec.europa.eu/programmes/horizon2020/en/area/environment-climate-action
([51]) https://ec.europa.eu/clima/policies/budget/life_en
([52]) https://www.interregeurope.eu
([53]) https://www.climate-kic.org
([54]) https://ec.europa.eu/agriculture/research-innovation/eip-agriculture_en
([55]) https://www.copernicus.eu/en
([56]) https://climate-adapt.eea.europa.eu

risk of food security in cases in which impacts occur rapidly, but it remains unclear if and how trade policies can support climate change adaptation strategies and actions.

6.3 Promoting farm-level measures with benefits for mitigation and ecosystems

Farm-level adaptation addresses the specific needs of farms. Implementation of adaptation measures depends on the specific climate impact, the economic situation of the farm, the size of the farms and the cultural background and education of the farmer. The flexibility mechanisms of CAP instruments allow for tackling the specific needs of farming systems somehow; however, in the current CAP, adaptation is implicitly included only in the actions and it is usually 'a by- product' of other (environmental) actions.

The potential adaptation measures proposed in this report cover the agricultural activities of arable farming, horticulture, viniculture and livestock farming. These measures should be implemented in a way that encourages better management of soils and water, which can provide co-benefits, helping adaptation, mitigation and other environmental objectives while also being economically viable. They aim to combine adaptation and mitigation practices to sustain resilient production, conserve soil and water resources, reduce droughts, pests and other climatic threats, and reduce emissions or increase carbon intake in soils.

To ensure proper uptake of adaptation measures, farm advisory services on adaptation are essential, making use of the growing availability of climate information. Capacity building and education are important for mitigating and adapting to climate change. In addition, a change in consumers' behaviour is needed in a way that ensures greater sustainability in the future. Changing diets and reducing food waste would contribute to this.

Enhanced efforts are needed to increase the uptake of measures at farm level by promoting multiple benefits: for farmers in terms of economic benefits and for the environment in terms of enhancing resilience and adaptive capacity. Adaptation measures need to be presented not as additional requirements but as solutions to enable farming in Europe to be sustainable in the long run. Making food production and its trade environmentally sustainable, and thereby more resilient to climate change, is possible, but it will require a major shift in strategies and policies, public behaviour and the use of already available knowledge.

Abbreviations, symbols and units

AgMIP	Agricultural Model Intercomparison and Improvement Project
AgriCLASS	Agricultural Climate Advisory Services
AVEMAC	Assessing Agriculture Vulnerabilities for the design of Effective Measures for Adaptation to Climate Change
BISE	Biodiversity Information System for Europe
C	Carbon
C3S	Copernicus Climate Change Service
CAP	Common agricultural policy
CCA	Climate change adaptation
CDS	Climate data store
CH_4	Methane
Climate-ADAPT	The European Adaptation Platform
CLIMATE-KIC	Knowledge and Innovation Communities for Climate
CMEF	Common Monitoring and Evaluation Framework
CMIP	Coupled Model Intercomparison Project
CO_2	Carbon dioxide
COP	Conference of the Parties
Copernicus	EU's Earth Observation Programme
CRF	Common Reporting Format
CSA	Climate-Smart Agriculture
DG AGRI	Directorate-General for Agriculture and Rural development
DG CLIMA	Directorate-General for Climate Action
DG JRC	Directorate-General - Joint Research Centre
DRR	Disaster risk reduction

DSS	Decision Support System
EAFRD	European Agricultural Fund for Rural Development
EAGF	European Agricultural Guarantee Fund
ECA	European Court of Auditors
ECMWF	European Centre for Medium-Range Weather Forecasts
EEA	European Environment Agency
EIP Water	European Innovation Partnership on Water
EIP-AGRI	European Innovation Partnership for Agricultural productivity and Sustainability
EP	European parliament
ERA4CS	European Research Area for Climate Services
ERA-NET	European Research Area NETwork
EbA	Ecosystem Based Adaptation
ESA	European Space Agency
ESTAT/EUROSTAT	Directorate-General of the European Commission responsible for statistical information
EU	European Union
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
EUNIS	European Nature Information System
EUR	Euro
FACCE-JPI	Joint Programming Initiative on Agriculture, Food Security and Climate Change
FAO	UN's Food and Agriculture Organisation
FAO-Adapt	FAO's programme on climate change adaptation
FAS	Farm Advisory System
FRMP	Flood Risk Management Plan
GACSA	Global Alliance for Climate-Smart Agriculture
GAEC	Good Agriculture and Environmental condition
GDP	Gross Domestic Product
GEM	General Equilibrium Models
GHG	Greenhouse gases
GP	Green papers

GPS	Global positioning system
GVA	Gross value added
H2020	EU Research and Innovation programme
HELIX	High-End cLimate Impacts and eXtremes
HNV	High nature value
HORIZON 2020	EU Research and Innovation programme
IAM	Integrated Assessment Models
IFOAM	International Federation of Organic Agriculture Movements
IMPRESSIONS	IMPacts and REsponses from high-end Scenarios: Strategies for Innovative SolutiONS
INTERREG	EU instrument supporting cooperation across borders through project funding
IPCC	Intergovernmental Panel on Climate Change
IPCC AR5	IPCC Fifth assessment report
ISI-MIP	Inter-Sectoral Impact Model Intercomparison Project
IST	Income stabilisation tool
JPI	Joint programming Initiative
JRC	Joint Research Centre
LEADER	Liaison entre actions de développement de l'économie rurale
LIFE+	EU's funding instrument for the environment and climate action
LULUCF	Land Use, Land Use Change and Forestry
MACSUR	Modeling European Agriculture with Climate Change for food Security
MAES	Mapping and Assessment of Ecosystems and their Services
MMR	Monitoring Mechanism Regulation
MS	The EU Member States
$MtCO_2e$	Mega Tonnes of CO_2 equivalent
N	Nitrogen
N2K	Natura 2000
N_2O	Nitrous oxide
NAP	National adaptation plan
NAS	National adaptation strategy

ND	Nitrates Directive
NECD	National Emissions Ceilings Directive
NGO	Non-governmental organization
NH_3	Ammonia
NO_3	Nitrate
NUTS	Nomenclature of Territorial Units for Statistics
OECD	Organisation for Economic Co-operation and Development
PEM	Partial Equilibrium Models
PESETA	Projection of Economic impacts of climate change in Sectors of the European Union based on bottom-up Analysis
PM	Particulate matter
PMEF	Performance monitoring and evaluation framework
RAP	Representative Agricultural Pathways
RBMP	River Basin Management Plans
RCP	Representative Concentration Pathway
RDP	Rural Development Programme
SBSTA	Subsidiary Body for Scientific and Technological Advice
SDG	Sustainable Development Goals
SEBI2020	Streamlining European Biodiversity Indicators
SFDRR	Sendai Framework for Disaster Risk Reduction
SIS	Sectoral Information System
SMR	Statutory mandatory requirement
SOLMACC	Strategies for Organic and Low-input-farming to Mitigate and Adapt to Climate Change
SPA	Shared Climate Policy Assumptions
SSP	Shared Socioeconomic Pathways
SWDs	Staff Working Documents
TFP	Total Factor Productivity
UAA	Utilised agricultural area
UNEP	United Nations Environment Programme

UNFCCC	United Nations Framework Convention on Climate Change
VISCA	Vineyards' Integrated Smart Climate Application
WB	Water body
WF	Water footprint
WFD	Water Framework Directive

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