Agri Adapt

• SUSTAINABLE ADAPTATION OF TYPICAL EU FARMING SYSTEMS TO CLIMATE CHANGE •

A1: Baseline reports for the 4 main EU Climate Risk Regions

LIFE15 CCA/DE/000072

March 2017

Bodensee Stiftung
Lake Constance Foundation

www.emu.ee
Eesti Maaülikool
Estonian University of Life Sciences

Fundación Global Nature

Solagro

0. Table of contents

1 Context

1.1 DEFINITIONS

Before addressing the observed and future climate change in Europe and their related impacts for the agricultural sector, it is important first to agree with each other about the exact definition of some key concept to avoid comprehension errors.

Climate

Climate in a narrow sense is usually defined as the **average weather**, or more rigorously, as the **statistical description** in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The classical period for averaging these variables is **30 years**, as defined by the World Meteorological Organization. The relevant quantities are most often surface variables such as temperature, precipitation, and wind. Climate in a wider sense is the state, including a statistical description, of the climate system (IPCC, 2014).

Climate change

Climate change refers to a **change in the state of the climate** that can be identified, e.g., by using statistical tests, by **changes in the mean and/or the variability** of its properties, and that **persists for an extended period**, typically decades or longer. Climate change may be due to natural internal processes or external forcings such as modulations of the solar cycles, volcanic eruptions, and persistent anthropogenic changes in the composition of the atmosphere or in land use. Note that the Framework Convention on Climate Change (UNFCCC), in its Article 1, defines climate change as: “a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods.” The UNFCCC thus makes a distinction between climate change attributable to human activities altering the atmospheric composition, and climate variability attributable to natural causes (IPCC, 2014).

Climate system

The climate system is the highly complex system consisting of **five major components**: the atmosphere, the hydrosphere, the cryosphere, the lithosphere, and the biosphere, and the interactions among them. The climate system evolves in time under the influence of its own internal dynamics and because of external forcings such as volcanic eruptions, solar variations, and anthropogenic forcings such as the changing composition of the atmosphere and land use change (IPCC, 2014).

Climate variability

Climate variability refers to **variations in the mean state** and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all spatial and temporal scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability) (IPCC, 2014).

Climate scenario

A plausible and often simplified representation of the future climate, based on an internally consistent set of climatological relationships that has been constructed for explicit use in investigating the potential consequences of anthropogenic climate change, often serving as input to impact models. Climate projections often serve as the raw material for constructing climate scenarios, but climate scenarios usually require additional information such as the observed current climate (IPCC, 2014).

Extreme weather event

An extreme weather event is an event that is **rare at a particular place and time** of year. Definitions of rare vary, but an extreme weather event would normally be as rare as or rarer than the 10th or 90th percentile of a probability density function estimated from observations. By definition, the characteristics of what is called extreme weather may vary from place to place in an absolute sense. When a pattern of extreme weather persists for some time, such as a season, it may be classed as an extreme climate event, especially if it yields an average or total that is itself extreme (e.g., drought or heavy rainfall over a season) (IPCC, 2014).

Heat weave

A period of abnormally and uncomfortably hot weather (IPCC, 2014).

Projection

A projection is a potential **future evolution** of a quantity or set of quantities, often computed with the aid of a model. Unlike predictions, projections are conditional on assumptions concerning, for example, future socioeconomic and technological developments that may or may not be realized. See also Climate prediction and Climate projection (IPCC, 2014).

Resilience

The capacity of social, economic, and environmental systems t**o cope with a hazardous event or trend** or disturbance, responding or reorganizing in ways that **maintain their essential function**, identity, and structure, while also maintaining the capacity for adaptation, learning, and transformation (IPCC, 2014).

Risk

The potential for consequences where something of value is at stake and where the outcome is uncertain, recognizing the diversity of values. Risk is often represented as probability of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur. Risk results from the interaction of vulnerability, exposure, and hazard (IPCC, 2014).

Vulnerability

The propensity or predisposition to be **adversely affected**. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt (IPCC, 2014).

In addition to these key concept definitions, explanations about Couple Model Intercomparison Project (CMIP), Representative Concentration Pathways (RCPs) and SRES scenarios are available in the Glossary.

1.2 WORLD CONTEXT

The following facts within this chapter are all extracted from the WG II AR5 (IPCC, 2014), Chapter 7 "Food Security and Food Production Systems".

The **effects of climate change** on crop and terrestrial food production **are evident** in several regions of the world (high confidence). **Negative impacts** of climate trends have been **more common** than positive ones. Positive trends are evident in some high latitude regions (high confidence).

Studies have documented a large **negative sensitivity of crop yields** to **extreme daytime temperatures** around 30 °C. These sensitivities have been identified for several crops and regions and exist throughout the growing season (high confidence). Several studies report that **temperature trends** are important for determining both **past and future impacts** of climate change on crop yields at sub-continental to global scales (medium confidence). At scales of individual countries or smaller, **precipitation projections** remain important but **uncertain factors** for assessing future impacts (high confidence).

Evidence confirms the **stimulatory effects of carbon dioxide** (CO_2) in most cases and the **damaging effects** of elevated **tropospheric ozone** (O_3) on crop yields (high confidence). Experimental and modelling evidence indicates that interactions between CO_2 and O_3, mean temperature and extremes, water, and nitrogen are nonlinear and difficult to predict (medium confidence).

Changes in climate and CO_2 concentration will enhance the distribution and increase the competitiveness of agronomically important and **invasive weeds** (medium confidence). Rising CO_2 may reduce the effectiveness of some herbicides (low confidence). The effects of climate change on **disease pressure** on food crops are uncertain, with evidence pointing to changed geographical ranges of pests and diseases but less certain changes in disease intensity (low confidence).

For the major crops (wheat, rice, and maize) in tropical and **temperate regions**, climate change **without adaptation** is projected to **negatively impact** aggregate production for local temperature increases of 2 °C or more above late-20th-centurylevels, although individual locations may benefit (medium confidence) (see Figure 1). Projected **impacts vary across** crops and regions and adaptation scenarios, with about 10 % of projections for the period 2030–2049 showing yield gains of more than 10 %, and about 10 % of projections showing yield losses of more than 25 %, compared to the late 20th century. After 2050 the risk of more severe yield impacts increases and depends on the level of warming: crop production to be consistently and negatively affected by climate change in the future in low-latitude countries, while climate change may have **positive or negative effects in northern latitudes** (high confidence). Climate change is projected to **progressively increase inter-annual variability** of crop yields in many regions. These projected impacts will occur in the context of rapidly rising crop demand.

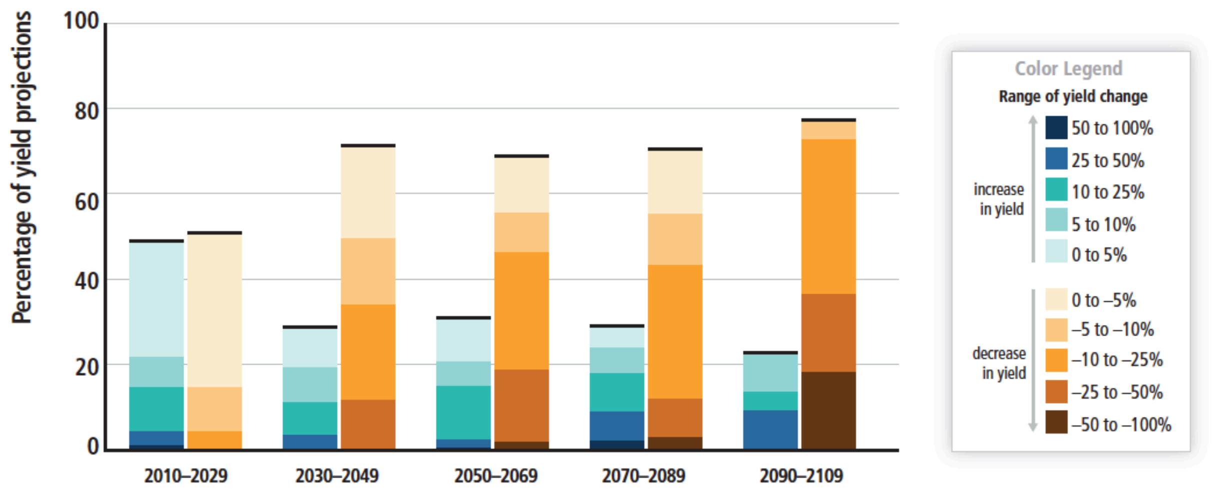


Figure TS.9 | Summary of projected changes in crop yields, due to climate change over the 21st century. The figure includes projections for different emission scenarios, for tropical and temperate regions, and for adaptation and no-adaptation cases combined. Relatively few studies have considered impacts on cropping systems for scenarios where global mean temperatures increase by 4°C or more. For five timeframes in the near term and long term, data (n=1090) are plotted in the 20-year period on the horizontal axis that includes the midpoint of each future projection period. Changes in crop yields are relative to late-20th-century levels. Data for each timeframe sum to 100%. [Figure 7-5]

Figure 1: Projected change in crops yields due to climate change in the 21st century (IPCC, 2014)

Earlier flowering and maturity have been observed (robust evidence, high agreement) worldwide in **grapes and apples**. For perennial crops, **winter chill accumulation** that is important to many fruit and nut trees is projected to continue its decline. Reductions in suitability for grapevine are expected in most of the wine-producing regions. **Wine grape production and quality** will be affected in Europe, USA, Australia.

In comparison to crop production, considerably less work has been published on observed impacts for other food production systems, such as **livestock**. The relative lack of evidence reflects a lack of study in this topic, but not necessarily a lack of real-world impacts of observed climate trends. A study of **blue-tongue virus**, an important ruminant disease, evaluated the effects of past and future climate trends on transmission risk, and concluded that climate changes have facilitated the recent and rapid spread of the virus **into Europe. Ticks** that carry zoonotic diseases have also likely changed distribution as a consequence of past climate trends.

1.3 EUROPEAN CONTEXT

1.3.1 Climate zone

In the WGII AR5 (IPCC, 2014), the European region is divided into five sub-regions: Atlantic, Alpine, Southern, Northern, and Continental. The sub-regions are derived by aggregating the climate zones developed by Metzger et al. (2005) and therefore represent geographical and ecological zones rather than political boundaries (see Figure 2).

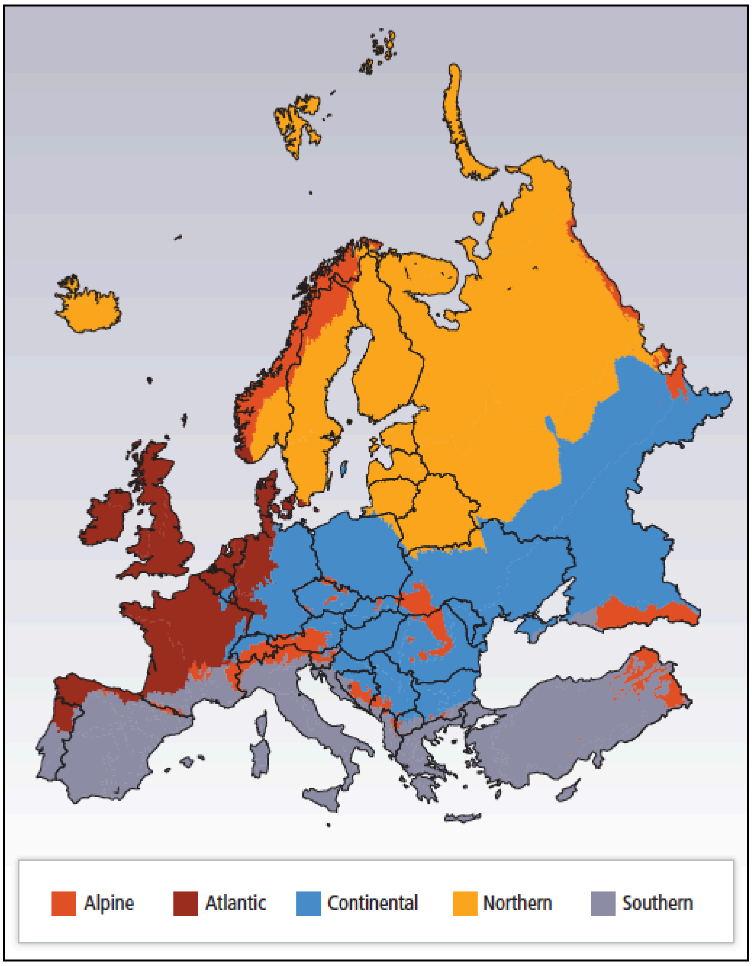


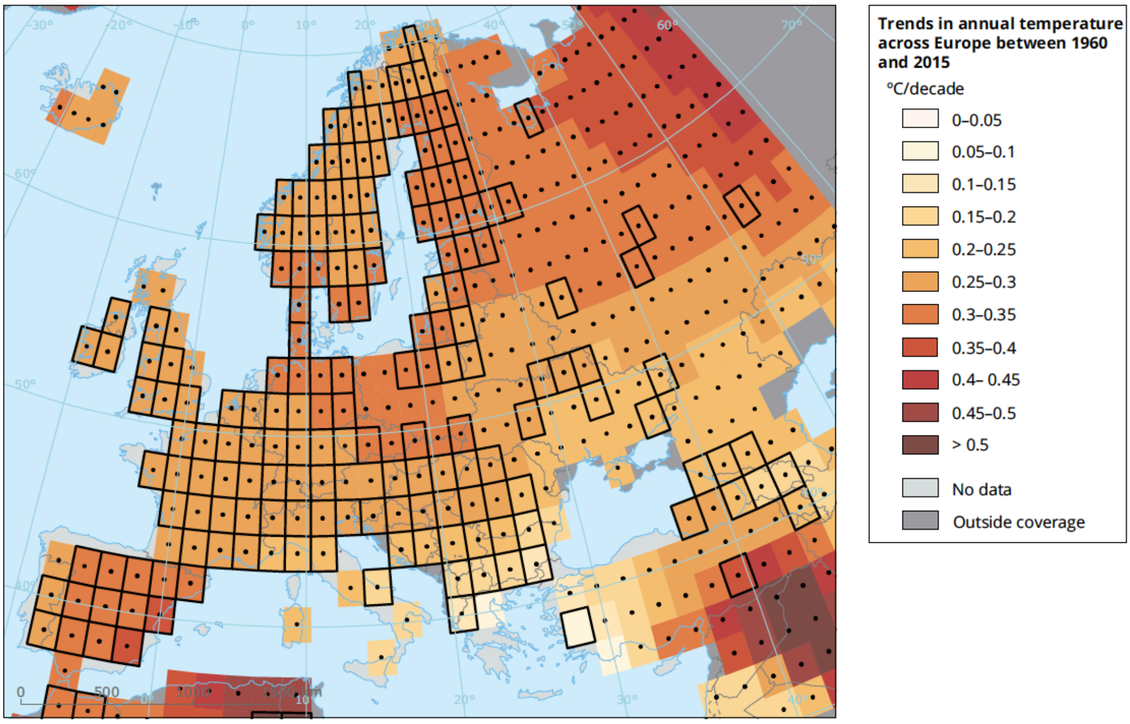
Figure 2: Climate Zones in Europe (IPCC, 2014)

1.3.2 Observed Climate Change

Observed climate trends and future climate projections show regionally varying changes in temperature and rainfall in Europe (high confidence), in agreement with Fourth Assessment Report (AR4) findings, with projected **increases in temperature** throughout Europe and **increasing precipitation** in Northern Europe and **decreasing precipitation** in Southern Europe (IPCC, 2014).

The average temperature in Europe has continued to increase since AR4, with regionally and seasonally different rates of warming being **greatest in high latitudes in Northern Europe**. Since the 1980s, warming has been strongest over Scandinavia, especially in winter, whereas the Iberian Peninsula warmed mostly in summer (IPCC, 2014).

According to three different observational records of the annual global average near-surface (land and ocean) temperature, the decade from 2006 to 2015 was **0.83 °C** to **0.89 °C** warmer than the preindustrial average. This makes it the **warmest decade** on record. 15 of the 16 warmest years on record have occurred since 2000, and **2015 was the warmest year** on record - around 1 °C warmer than the pre-industrial period (EEA, 2016).
Over the decade 2006-2015, the rate of change in global average surface temperature was between **0.10** and **0.24 °C** per decade. This is close to the indicative limits of 0.2 °C/decade (EEA, 2016).
The average annual temperature of the European land area, for the decade from 2006–2015, was around **1.5 °C** above the pre-industrial level. This makes it the warmest decade on record. Moreover, 2014 and 2015 were **the joint warmest years in Europe** since instrumental records began (EEA, 2016).

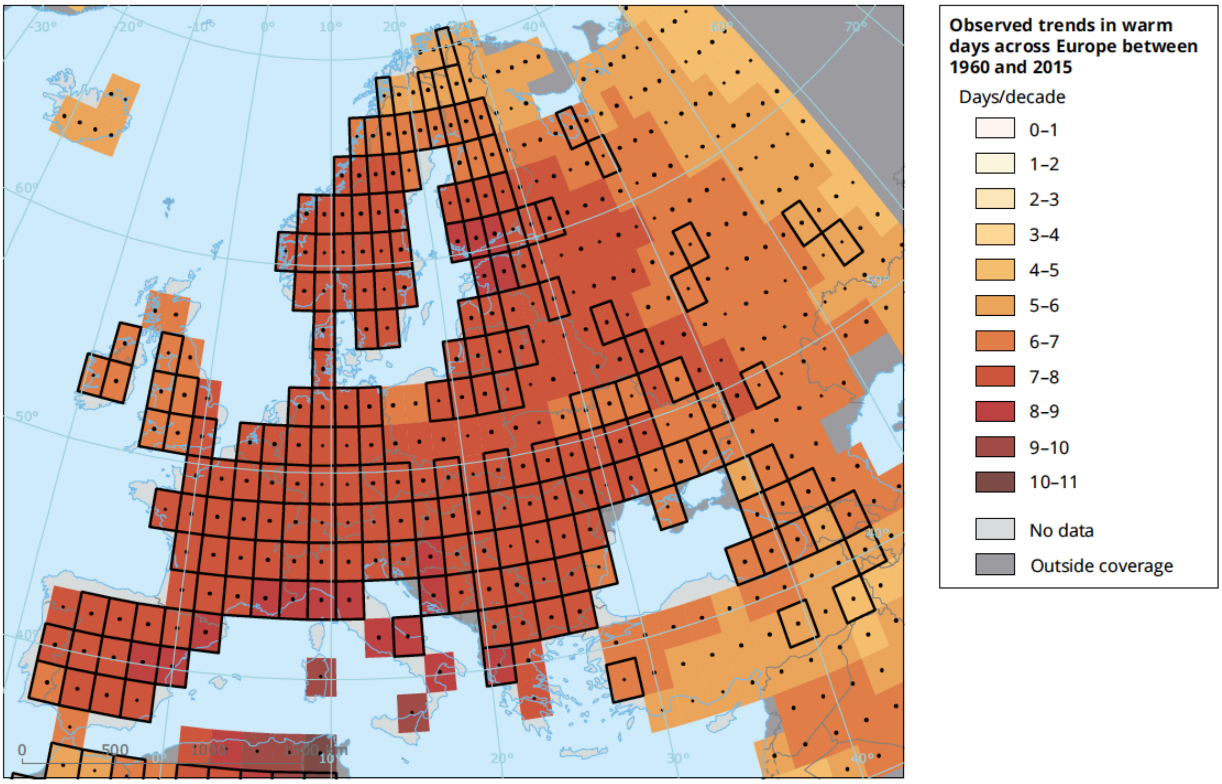


Note: Grid boxes outlined with solid black lines contain at least three stations and so are likely to be more representative of the grid box than those that are not outlined. Significance (at the 5 % level) of the long-term trend is shown by a black dot (which is the case for almost all grid boxes in this map).

Source: EEA and UK Met Office, based on the E-OBS dataset (updated from Haylock et al., 2008).

Figure 3: Trends in annual temperature across Europe between 1960 and 2015 (EEA, 2016)

Since 1950, **high-temperature extremes** (hot days, tropical nights, and heat waves) have become **more frequent**, while **low-temperature extremes** (cold spells, frost days) have become **less frequent** (IPCC, 2014).
Since 1880, the average **length of summer heat waves** over western Europe has doubled and the frequency of **hot days has almost tripled**. The number of warm days (those exceeding the 90 percentile threshold of a baseline period) **have almost doubled** since 1960 across the European land area (EEA, 2016).

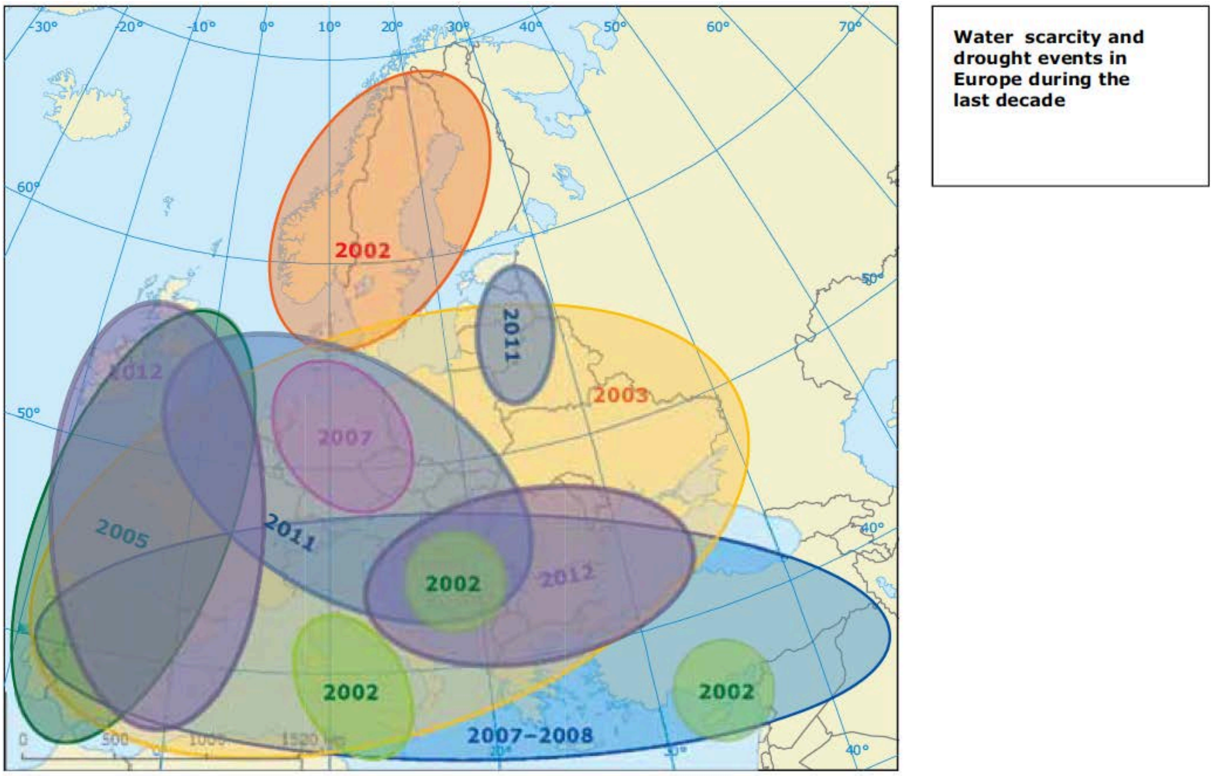


Note: Warm days are defined as being above the 90th percentile of the daily maximum temperature centred on a five-day window for a reference period. Grid boxes outlined with solid black lines contain at least three stations and thus trends are more robust. High confidence in the long-term trend (at the 5 % level) is shown by a black dot (which is the case for all grid boxes in this map). The reference period is 1971–2000.

Source: EEA and UK Met Office, based on HadEX2 (updated from Donat, Alexander, Yang, Durre, Vose, Dunn et al., 2013).

Figure 4: Observed trends in warm days across Europe between 1960 and 2015 (EEA, 2016)

Europe has experienced **several extreme heatwaves** since the year 2000 (2003, 2006, 2007, 2010, 2014 and 2015), such as the catastrophic drought associated with the **2003** summer heat wave in central parts of the continent and the **2005** drought in the Iberian Peninsula. Severity and frequency of droughts appear to have increased in parts of Europe, in particular in southern Europe (EEA, 2012).



Source: ETC-LUSI; Tallaksen (personal communication).

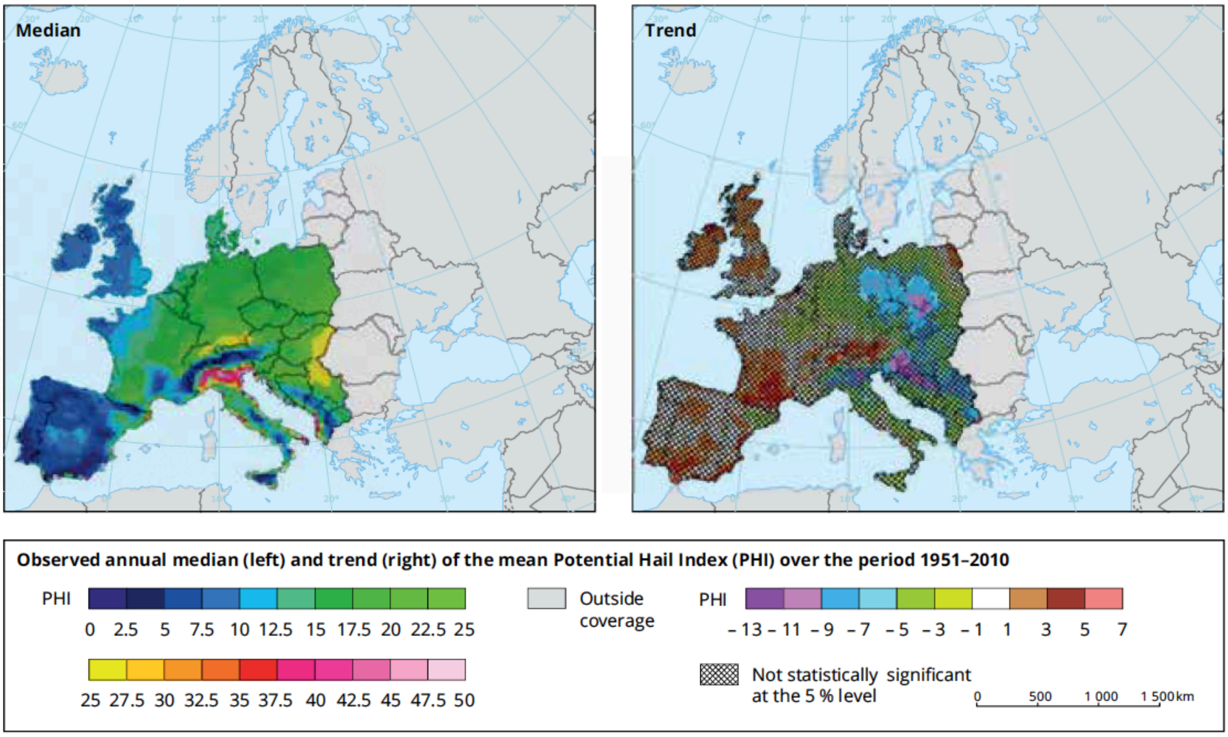
Figure 5: Water scarcity and drought events in Europe during the last decade (EEA, 2012)

Since 1950, **annual precipitation has increased in Northern Europe** (up to +70 mm per decade), and decreased (up to 70 mm per decade) **in parts of Southern Europe**. Seasonal precipitation trends show an increase in **winter precipitation in northern Europe** and a **decrease in southern Europe**, albeit with large interannual variations (EEA, 2012). The intensity of heavy precipitation events in summer and winter have increased in northern and north-eastern Europe since the 1960s. Different indices show diverging trends for south-western and southern Europe (EEA, 2016).

Winter snow cover extent has a high interannual variability and a non-significant negative trend over the period 1967–2007. Snow cover extent in the Northern Hemisphere has fallen by 7 % in March and 11 % in April during the past 4 decades. In winter and autumn no significant changes have occurred (EEA, 2012).

Mean wind speeds have declined over Europe over recent decades (IPCC, 2014). Storm location, frequency and intensity have shown considerable decadal variability across Europe over the past century, such that no significant long-term trends are apparent (EEA, 2016).

Hail events are among the most costly weather-related extreme events in several European regions, causing for example substantial damage to crops. The **number of hail events is highest** in mountainous areas and pre-Alpine regions. Since 1951, increasing hail trends have been noted in southern France and Austria, and decreasing (but not statistically significant) trends have been noted in parts of eastern Europe (EEA, 2016).

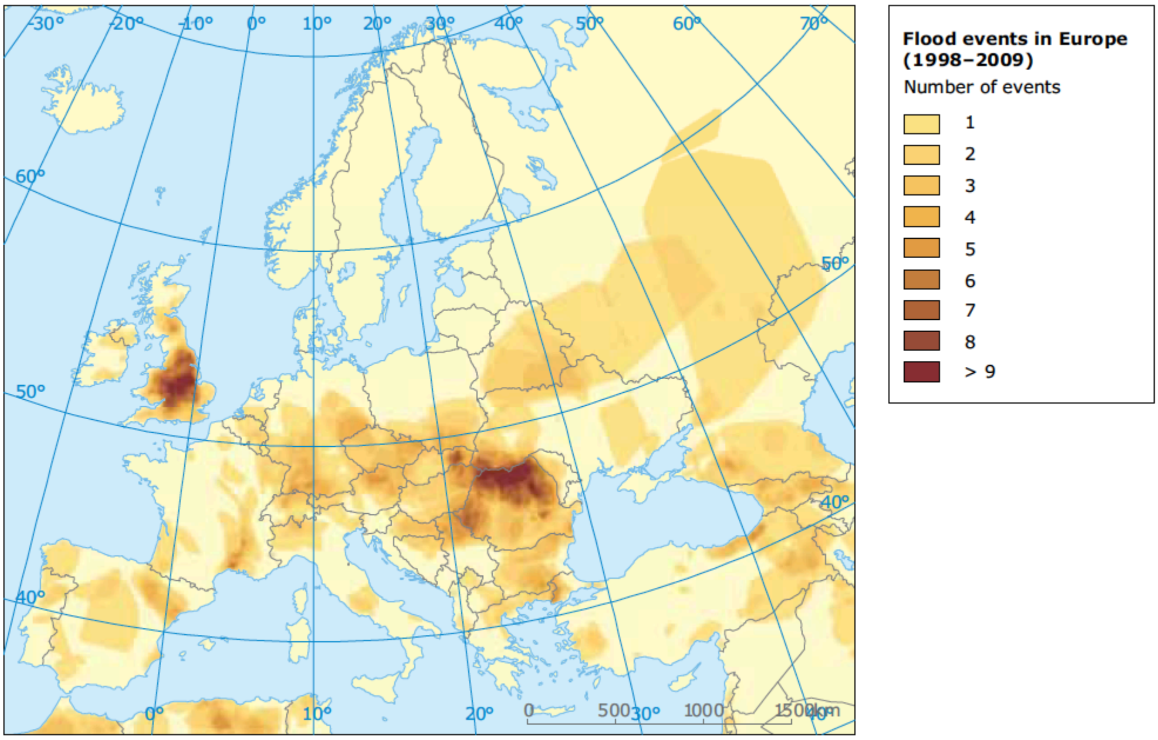


Note: Trends that are not significant at the 5 % level are cross-hatched. Significant trends are found only for values below a PHI of – 5 over the period.

Source: Based on the logistic hail model (Mohr, Kunz, and Geyer, 2015) and reanalysis data from NCEP-NCAR (Kalnay et al., 1996).

Figure 6: Observed annual median and trend of the mean Potential Hail Index (PHI) over the period 1951-2010 (EEA, 2016)

More than 325 major **river floods** have been reported for Europe since 1980, of which more than 200 have been reported since 2000. The rise in the reported number of flood events over recent decades results mainly from better reporting and from land-use changes (EEA, 2012).

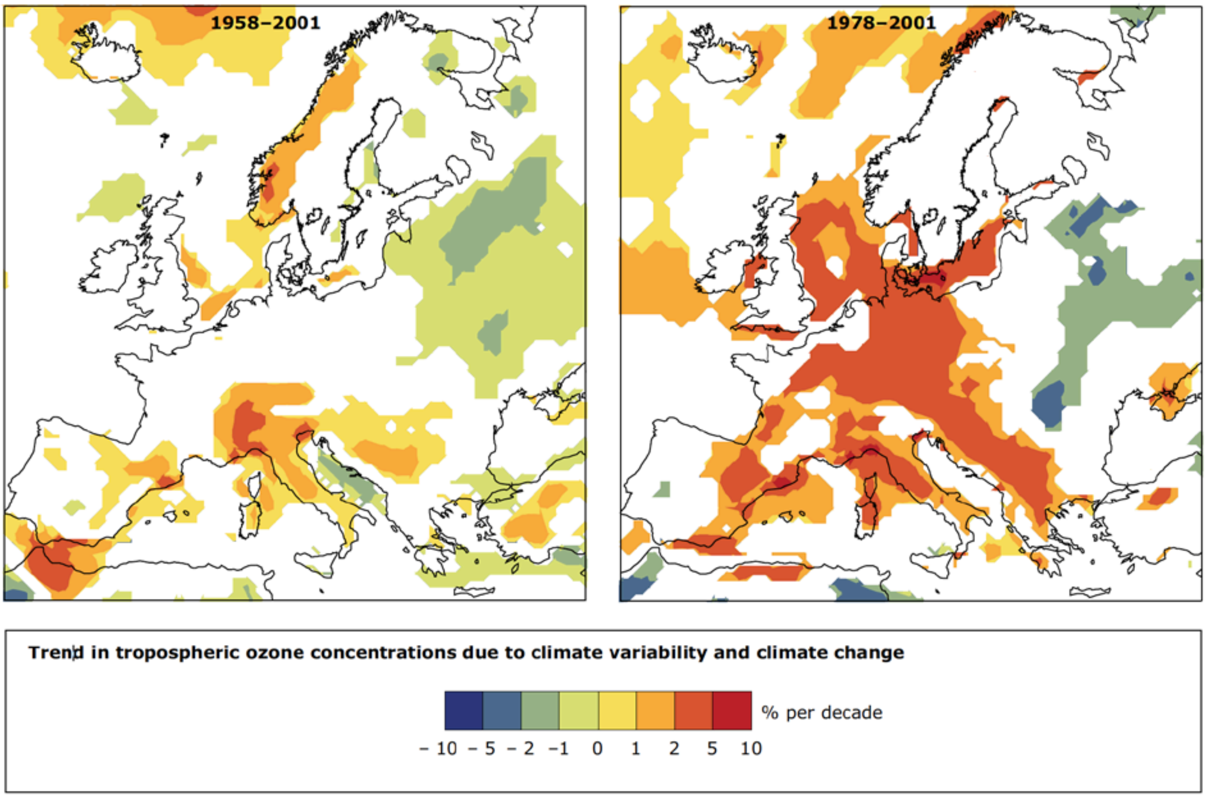


Source: EEA, based on Dartmouth Flood Observatory, 2012.

Figure 7: Occurrence of floods in Europe between 1998 and 2009 (EEA, 2012)

Ozone is a greenhouse gas, but **ground level ozone** is primarily an air pollutant, which is of high concern in Europe. Concentrations of ground‑level ozone are determined by both precursor emissions and meteorological conditions, which also influence the transport of ozone and its precursors between continents. Ground-level ozone is highly reactive and therefore **harmful to vegetation**, materials and human health.

Ozone precursor emissions in Europe have been cut substantially recently whereas average ozone concentrations in Europe have largely stagnated. Formation of tropospheric ozone from increased concentrations of CH_4 may also contribute to the sustained ozone levels in Europe (EEA, 2012).



Source: Andersson et al., 2007, in EEA, 2008.

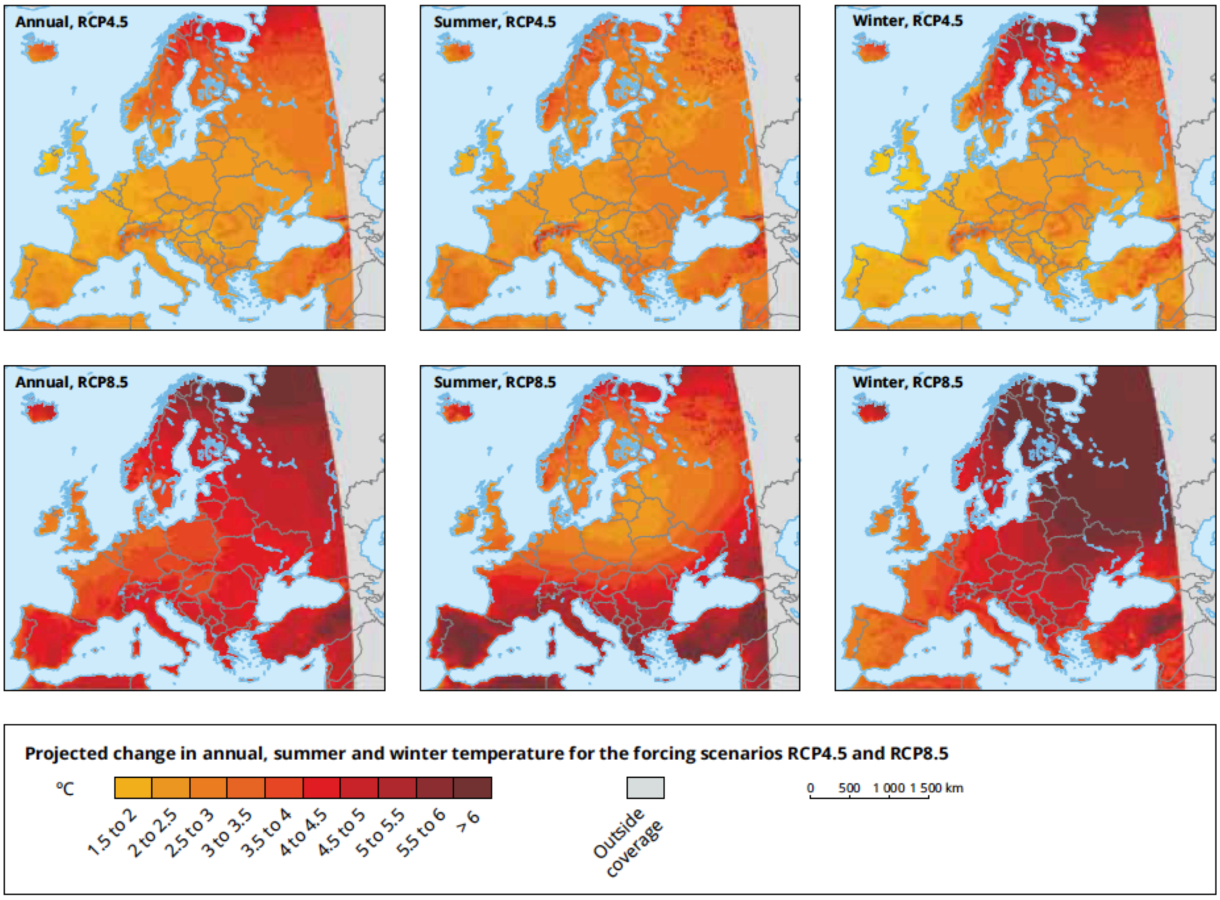
Figure 8: Modelled change in tropospheric ozone concentrations over Europe, 1958-2001 and 1978-2001

1.3.3 Projected Climate Change and Climate Extreme

Climate Change

Climate models show significant agreement for all emission scenarios **in warming** (magnitude and rate) all over Europe, with strongest warming projected in Southern Europe in summer, and in Northern Europe in winter. Even under an average global temperature increase **limited to 2 °C** compared to preindustrial times, the climate of Europe is simulated to **depart significantly in the next decades** from today's climate (IPCC, 2014).

Climate models project further increases in global average temperature over the 21st century. For the period 2081-2100 (relative to 1986-2005), increases of between **0.3 °C** and **1.7 °C** for the lowest emissions scenario (RCP2.6 (Representative Concentration Pathway)), and between 2.6 °C and 4.8 °C for the highest emissions scenario (RCP8.5) are estimated (EEA, 2016).
By the end of this century (2071-2100 relative to 1971-2000), annual average land temperature over Europe is projected to increase in the range of 1 °C to 4.5 °C under RCP4.5, and 2.5 °C to 5.5 °C under RCP8.5. This is more than the global average. The strongest warming is projected over northeastern Europe and Scandinavia in winter and southern Europe in summer (EEA, 2016).

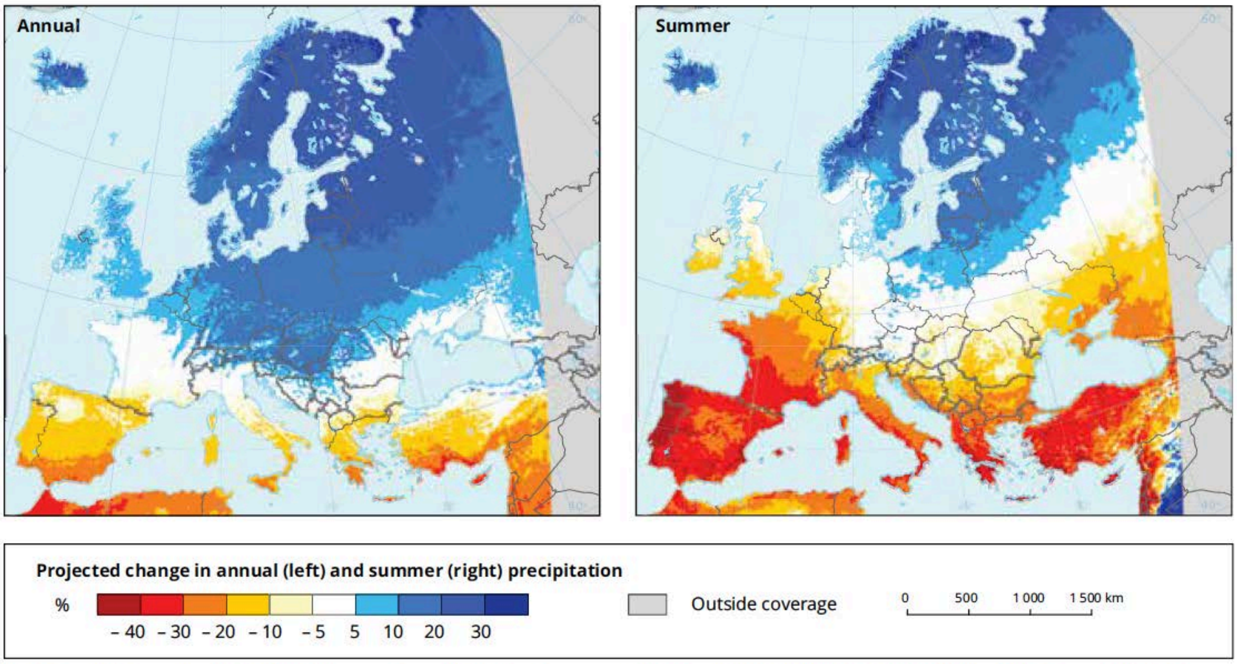


Note: This map shows projected changes in mean annual (left), summer (middle) and winter (right) near-surface air temperature (°C) in the period 2071–2100 compared with the baseline period 1971–2000 for the forcing scenarios RCP4.5 (top) and RCP8.5 (bottom). Model simulations are based on the multi-model ensemble average of many different combined GCM–RCM simulations from the EURO-CORDEX initiative.

Source: EURO-CORDEX (Jacob et al., 2014).

Figure 9: Projected changes in mean annual, summer and winter temperature for the forcing scenarios RCP4.5 and RCP8.5 (EEA, 2016)

Precipitation signals vary regionally and seasonally. Trends are less clear in Continental Europe, with agreement in **increase in Northern Europe** and **decrease in Southern Europe** (medium confidence). Precipitation is projected to decrease in the summer months up to southern Sweden and increase in winter, with more rain than snow in mountainous regions. In Northern Europe, **a decrease of long-term mean snowpack** (although snow-rich winters will remain) toward the end of the 21st century is projected. There is lack of information about past and future changes in hail occurrence in Europe. Changes in future circulation patterns and mean wind speed trends are uncertain in sign.



Note: This map shows projected changes in annual (left) and summer (right) precipitation (%) in the period 2071–2100 compared with the baseline period 1971–2000 for the forcing scenario RCP8.5. Model simulations are based on the multi-model ensemble average of many different RCM simulations from the EURO-CORDEX initiative.

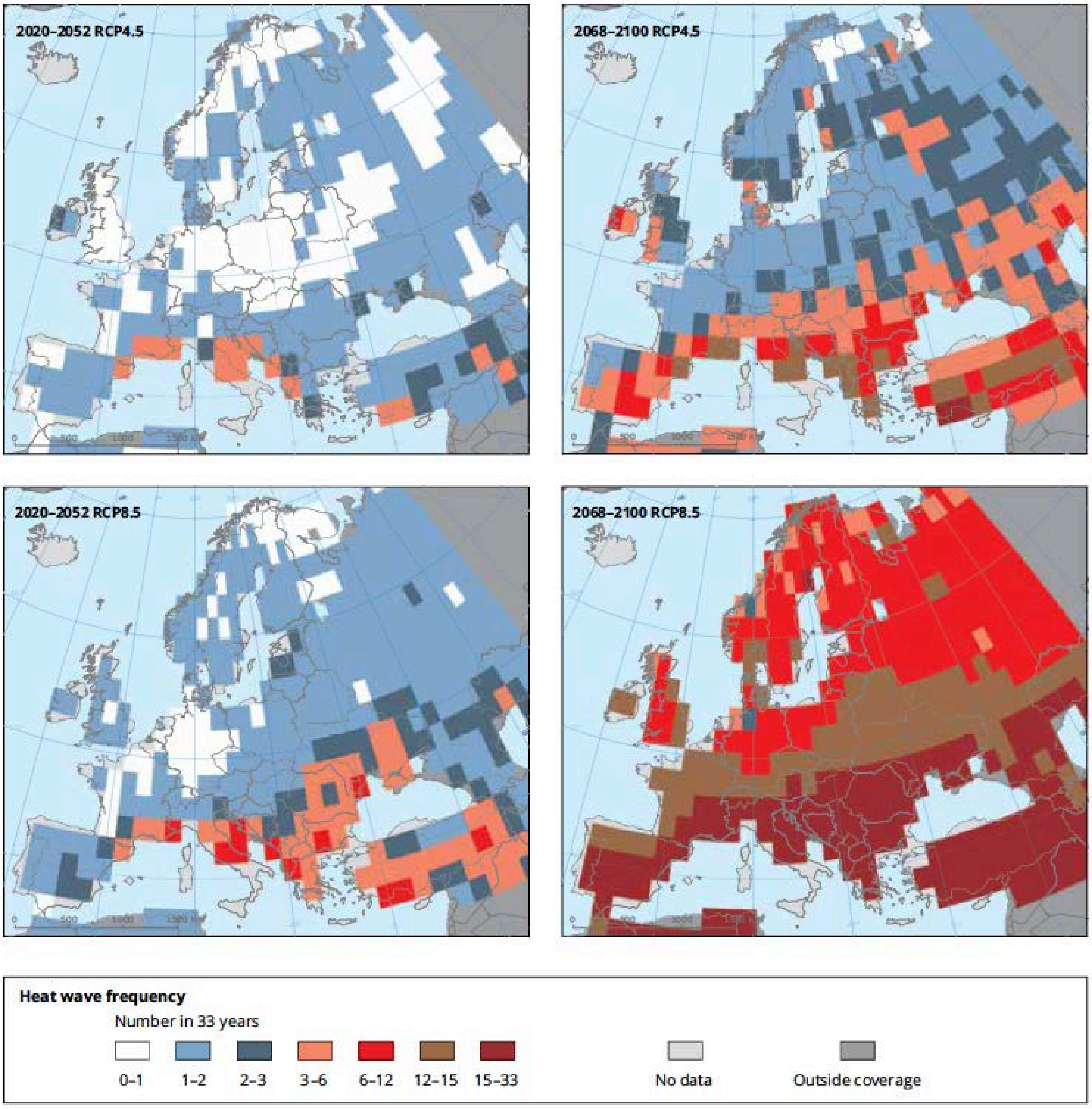
Source: EURO-CORDEX (Jacob et al., 2014).

Figure 10: Projected changes in annual and summer precipitation (EEA, 2016)

Climate Extreme

Climate projections show a marked increase in **high temperature extremes** (high confidence), **meteorological droughts** (medium confidence), and **heavy precipitation events** (high confidence), with variations across Europe, and small or **no changes in wind speed extremes** (low confidence) except increases in winter wind speed extremes over Central and Northern Europe (medium confidence) (IPCC, 2014).

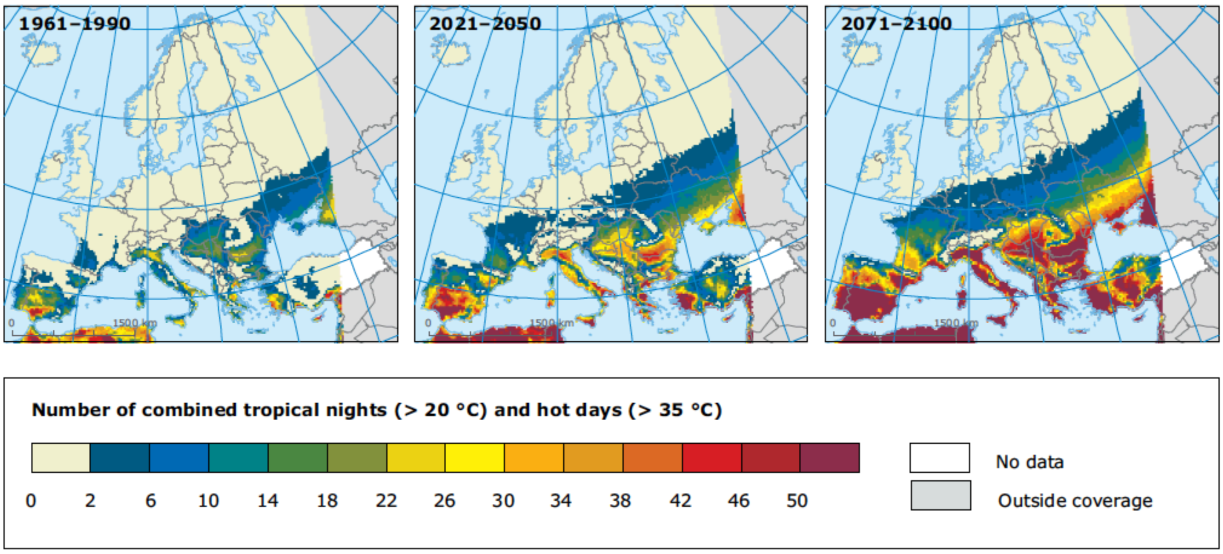
There is a general high confidence concerning changes in **temperature extremes** (toward increased number of warm days, warm nights, and heat waves).
Extreme high temperatures are projected to become more frequent and last longer across Europe over the 21st century (EEA, 2012). Under a high emissions scenario (RCP8.5), very extreme heat waves as strong as in the 2000 or even stronger are projected to occur as often **as every two years** in the second half of the 21st century. The impacts will be particularly strong in southern Europe (EEA, 2016).



Note: Very extreme heat waves are defined as having a HWMI above 8. For comparison, the 2003 western European heat wave had an average HWMI of around 3, and the 2010 eastern European heat wave had an average HWMI of around 5. The upper maps show the median number of very extreme heat waves in a multi-model ensemble of GCMs of the near future (2020–2052) and the latter half of the century (2068–2100) under the RCP4.5 scenario. The lower maps are for the same time periods but under RCP8.5.

Source: Adapted from Russo et al., 2014.

Figure 11: Number of very extreme heat waves in future climates under two different climate forcing scenarios (EEA, 2016)

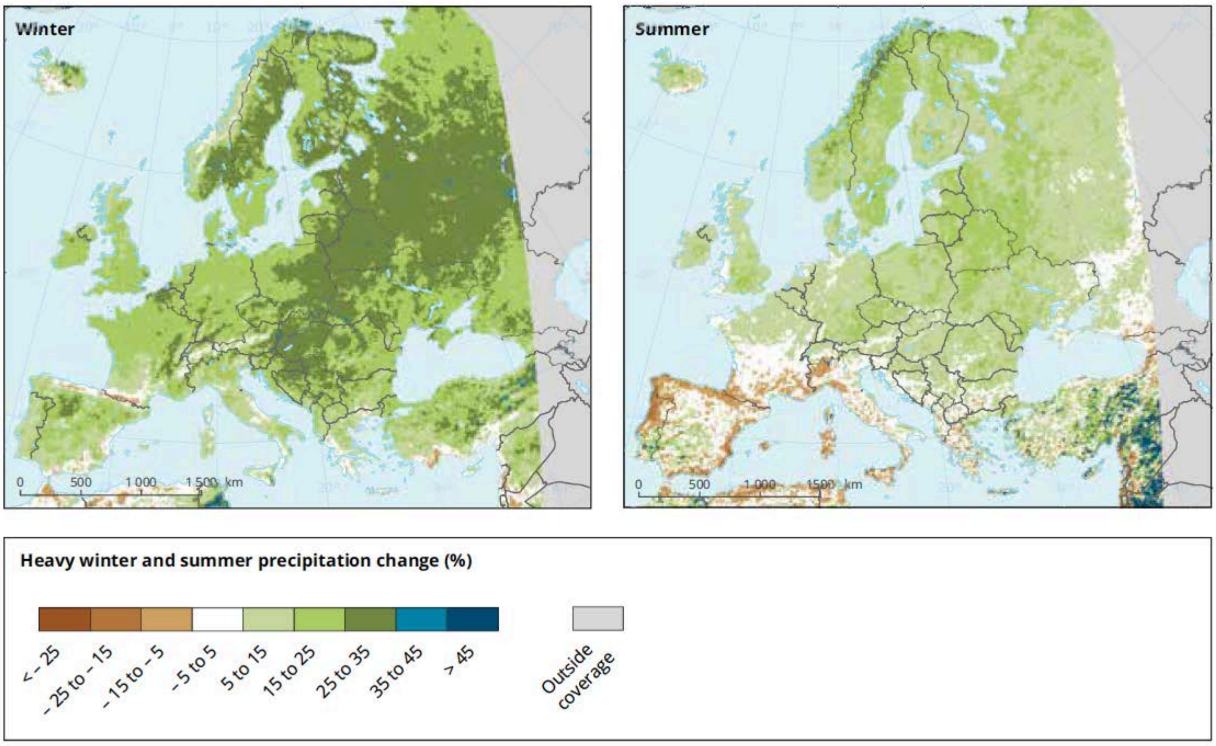


Note: Extreme high temperatures are represented by the combined number of hot summer (June–August) days (TMAX > 35 °C) and tropical nights (TMIN > 20 °C). All projections are the average of six regional climate model (RCM) simulations of the EU ENSEMBLES project using the IPCC SRES A1B emission scenario for the periods 1961–1990, 2021–2050 and 2071–2100.

Source: Fischer and Schär, 2010. © Nature Publishing Group. Reprinted with permission.

Figure 12: Projections of extreme high temperatures (EEA, 2012)

Projections show **an increase in heavy daily precipitation in most parts of Europe in winter**, by up to 35 % during the 21st century. Heavy precipitation in winter is projected to increase over most of Europe, with increases of up to 30 % in north-eastern Europe. In summer, an increase is also projected in most parts of Europe, but decreases are projected for some regions in southern and south- western Europe (EEA, 2016).



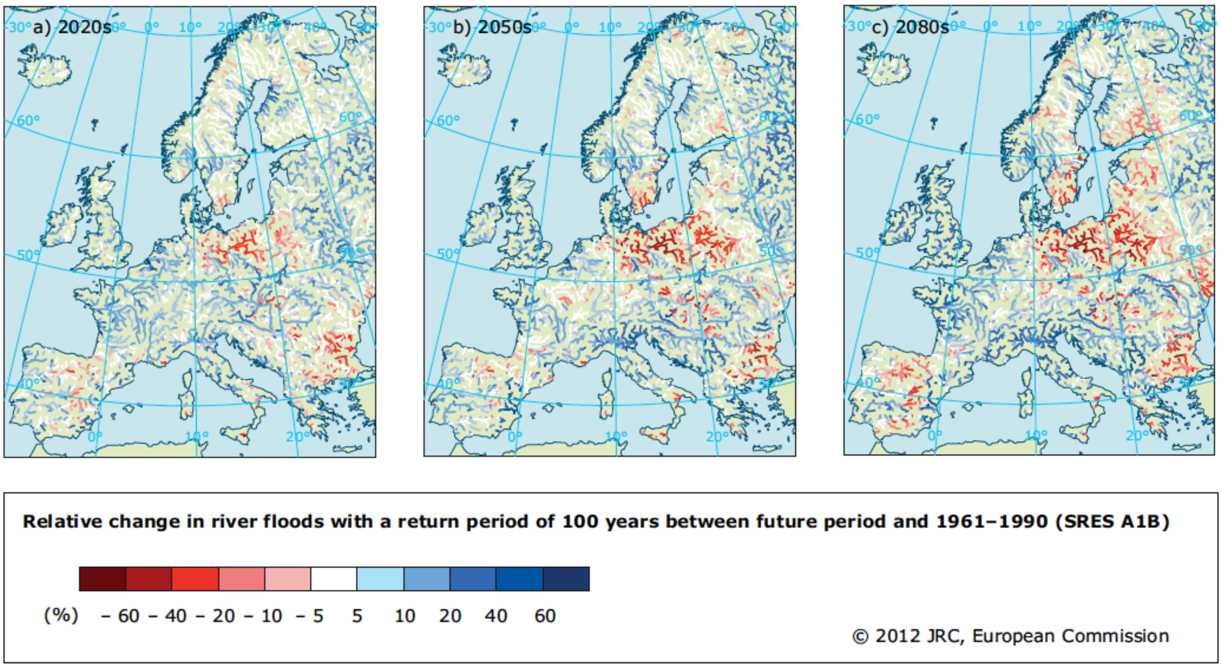
Note: This map shows projected changes in heavy daily precipitation (%) in winter and summer for 2071–2100, compared with the baseline period 1971–2000, for the RCP8.5 scenario based on the ensemble mean of different RCMs nested in different GCMs.

Source: EURO-CORDEX (Jacob et al., 2014).

Figure 13: Projected changes in heavy precipitation in winter and summer (EEA, 2016)

Global warming is projected to **intensify the hydrological cycle** and increase the occurrence and frequency of flood events in large parts of Europe. **Flash floods and pluvial floods**, which are triggered by local intense precipitation events, are likely to become **more frequent throughout Europe**. In regions with projected reduced snow accumulation during winter, the risk of early spring flooding could decrease. However, quantitative projections of changes in flood frequency and magnitude remain highly uncertain (EEA, 2012).

River flow drought: regions most prone to an increase in **drought hazard** are **southern** and **south-eastern Europe**, but minimum river flows are also projected to decrease significantly in many other parts of the continent, especially in summer.

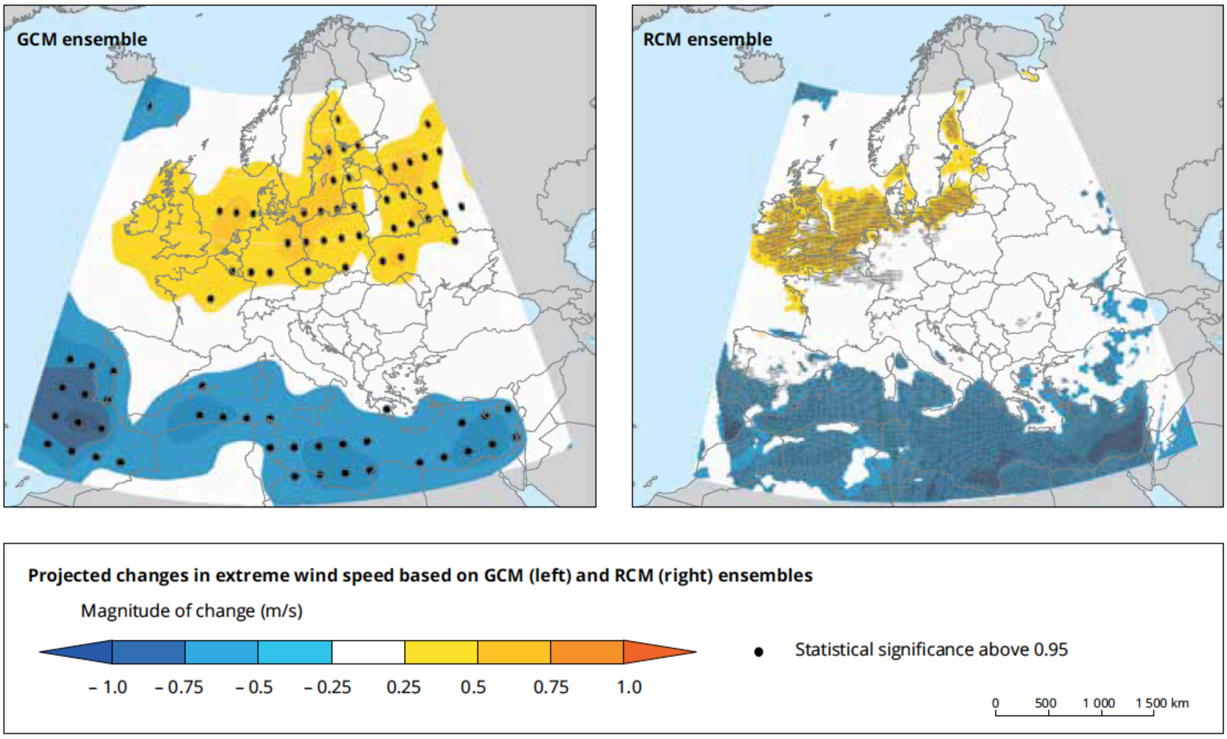


Note: Projected change in the level of a 100-year maximum level of river discharge between the reference period 1961–1990 and the 2020s (left), 2050s (centre) and the 2080s (right) based on an ensemble of 12 RCM simulations with LISFLOOD for the SRES A1B scenario.

Source: Rojas et al., 2012.

Figure 14: Projected change in river floods with return period of 100 years (EEA, 2012)

Climate change simulations show diverging projections on changes in the number of **winter storms** across Europe. However, most studies agree that the risk of severe winter storms, and possibly of severe autumn storms, will increase for the North Atlantic and northern, north-western and central Europe over the 21st century (EEA, 2016).



Note: This map shows the ensemble mean of changes in extreme wind speed (defined as the 98th percentile of daily maximum wind speed) for A1B (2071–2100) relative to 1961–2000. Left: based on nine GCMs. Right: based on 11 RCMs. Coloured areas indicate the magnitude of change (unit: m/s) and statistical significance at the 5 % level is shown by black dots.

Source: Adapted from Donat, Leckebusch et al., 2011. Reproduced with permission.

Figure 15: Projected changes in extreme wind speed based on GCM and RCM ensembles

Future projections of **hail events** are subject to large uncertainties, because small-scale hail events cannot be directly represented in global and regional climate models. However, model-based studies for central Europe show some agreement that hailstorm frequency will increase in this region (EEA, 2016).

Climate change is expected to affect **future ozone concentrations** due to changes in meteorological conditions, as well as due to increased emissions of specific ozone precursors (e.g. increased isoprene from vegetation under higher temperatures) and/or emissions from wildfires that can increase under periods of extensive drought. Most of the links between individual climate factors and ozone formation are well understood, but quantification of future levels of ground-level ozone remains uncertain due to the complex interaction of these processes. Available studies indicate that projected climate change affects different regions in Europe differently, by increasing average summer ozone concentrations in **southern Europe** and **decreasing** them over **northern Europe** and the Alps. Preliminary results indicate that in a long time perspective (2050 and beyond), envisaged emission reduction measures of ozone precursors have a much larger effect on concentrations of ground-level ozone than climate change. Climate change in combination with the emission reductions will influence the future levels of ground- level ozone.

1.3.4 Observed and future impacts for agriculture

Observed climate change in Europe has had wide ranging effects throughout the European region (see Table 1) including the distribution, phenology, and abundance of animal, fish, and plant species (high confidence) (IPCC, 2014).

Table 1: Observed changes in Agriculture (IPCC, 2014)

	Indicator	Change in indicator	Confidence in detection	Confidence in attribution to change in climate factors*	Key references	Section
Agriculture, fisheries, forestry, and bioenergy production	C_3 crop yield	CO_2-induced positive contribution to yield since pre-industrial for C_3 crops	*High confidence (high agreement, robust evidence)*	*High confidence (high agreement, robust evidence)*	Amthor (2001); Long et al. (2006); McGrath and Lobell (2011)	7.2.1
	Wheat yield	Stagnation of wheat yields in some countries in recent decades	*High confidence*	*Medium confidence*	Brisson et al. (2010); Kristensen et al. (2011); Lobell et al. (2011)	23.4.1
	Phenology—leaf greening	Earlier greening, earlier leaf emergence and fruit set in temperate and boreal climate	*High confidence (high agreement, robust evidence)*	*High confidence (high agreement, robust evidence)*	Menzel et al. (2006)	4.4.1.1

1.3.5 Generalities: climate characteristic, plant development and growth

The objective of this part is to identify and characterize the climate phenomena that impact on crop (annual or perennial) yields. From a physiological point of view (and if we consider only links between the crop and the atmosphere), a crop needs for its development and growth: radiation, CO_2, an accumulation of high temperatures, an accumulation of low temperatures (for some of them) and water.
The **development** corresponds to the whole qualitative changes that occur during the life of a crop. The phenological stages mark the development of a crop.
Growth is defined as the irreversible quantitative changes during the life of a crop: lengthening of internodes, cell multiplication... In agriculture, we can summarize the growth as biomass accumulation.

Radiation needs

The role of radiation is related to photosynthesis. Radiation brings to the crop the energy for photosynthesis. This energy is transmitted by the light in the form of photons (captured by the chlorophyll) then it is transformed into chemical energy (via transfer of electrons and protons in the chloroplasts) and accumulated in the form of sugar.

CO2 requirements

The carbon in CO_2 is one that will be accumulated in plants in the form of sugar. There are 2 families of plants that have different metabolic pathways of carbon fixation (via photosynthesis) called C3 plants and C4 plants. The C4 photosynthesis is particularly prevalent in tropical grasses (maize, sorghum, sugar cane). It differs from the mechanism by C3 carbon fixation mode during photosynthesis and the effectiveness of this step. It allows these plants to absorb all the CO_2 of the internal atmosphere of the plant. The efficiency of photosynthesis of C4 plants is significantly higher than that of C3 plants. This mechanism works even better if the light is bright and the temperature is high.
The increase of the CO_2 concentration can promote photosynthesis and increase biomass production and, hence yields of temperate “C3 species” from 10% to 20 %. As against this increase will have no impact on C4 plants.

Note: Plants breathe through tiny pores called **stomata** on the underside of their leaves. These pores allow carbon dioxide to enter and oxygen (and water) to exit. Plants open and close their stomata in response to changes in their environment so they can get the CO_2 they need and avoid drying out. The state of opening of the stomata is a **compromise between the loss of water and the assimilation of CO_2 from the ambient air**. For example, if the water is not sufficiently available, the resulting stomatal closure also affects photosynthesis by preventing gas exchange. This phenomenon could be compensated by an increasing in CO_2 concentration in ambient air.

High temperature requirements

The temperature is the engine of development of plants. **Development** is governed primarily by temperature (concept of Growing Degree Days – **GDD***). The temperature will play on the speed of development of culture and therefore cycle times (including grain filling and therefore yield). Each plant (and each variety) has its own thermal requirements: a corn 1 700 GDD will need to reach a point of harvest (Tbase 6 °C.) winter wheat will need GDD 2 350 (Tbase 0 °C.) to reach ripening.

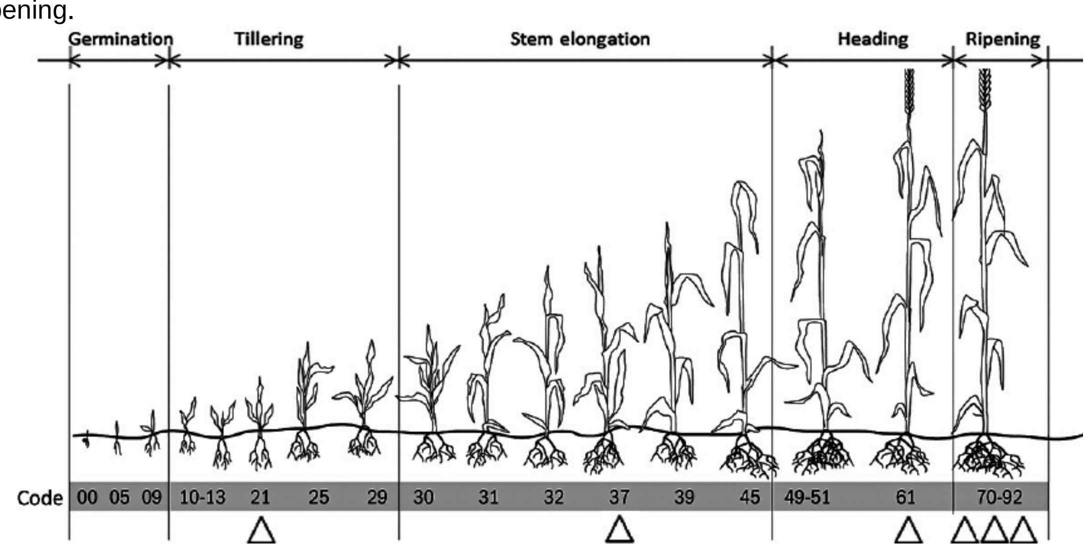


Figure 16: The different phenological stages of wheat (GDD needs: ear (1 cm) = 1100 GDD, end od ripening = 2350 GDD, Tbase 0 °C.)

* Growing Degree Days (GDD), also called growing degree units (GDUs), are a heuristic tool in phenology. GDD are a measure of heat accumulation used by farmers to predict plant and animal development rates such as the date that a flower will bloom, an insect will emerge from dormancy, or a crop will reach maturity. GDD are calculated by taking the integral of warmth above a base temperature (Tbsae). A simpler, approximately equivalent formulation uses the average of the daily maximum and minimum temperatures compared to a Tbase. As an equation:

-

It must be noted that beyond a temperature of 30 °C. most crops slow their development. Increasing the temperature may therefore lead to a shortening of the vegetative cycle

Annual crops sown in the autumn (wheat, rapeseed, ...) generally require lower temperatures to bloom in spring. The physiological process responsible for this behaviour is called "**vernalization**". To switch from vegetative **to the floral state**, winter cereals need to stay at sufficiently low temperatures during their juvenile stage. This is the vernalization phase that can be defined as the acquisition or accelerating the ability to flower after a cold treatment. This process is done without visible morphological changes and requires optimal temperatures between 3 and 10 °C (average daily temperatures). Outside this range, it is slowed or stopped if temperatures drop below - 4 °C or exceed 17 °C.
For most perennial plant species grown in our climate, lower night temperatures and decreasing photoperiod in the fall cause **dormancy**. Stopping this rest period is conditioned by many factors including cold temperatures. This period of development is known as the "cold need" (for breaking dormancy) which is an essential characteristic of woody species in temperate regions. This need is often evaluated by a sum of cold (sum of temperatures below 7 °C).

The cold requirement (for breaking dormancy) varies from one species to another and from one variety to another within the same species:

- Apple: 1 200-1 700 hours of cold (< 7 °C.) to break dormancy
- Cherry: 1 100-1 300 hours of cold (< 7 °C.)
- Apricot: 700-1 000 hours of cold (< 7 °C.)
- Almond: 200-500 hours of cold (< 7 °C.)
- Fig tree: 200 hours of cold (< 7 °C.)

Rising temperatures can therefore reduce the accumulation of cold temperatures and have negative impacts on flowering crops and / or buds of woody species.

Water requirements

Water is the plant growth factor. Growth is not regulated by many factors such as water sufficiency (or water stress), stomatal regulation or evapotranspiration.
A lack of water has a negative impact on the production of biomass. Excess water (during a long period) can lead to root suffocation phenomenon.

Key climatic parameters for crops

To simplify the approach for classifying the impact of climate on plants, it has been decided to select **four major weather events** that directly or indirectly affect yields of major crops (perennial annual):

- **Water deficit (during growth period)**
- **Excess water**
- **High Temperature**
- **Low Temperature**

In addition to the long-term changes of the four major weather events above, frequency of **extreme weather events** (hail, late frost, storms, ...) has also to be considered.

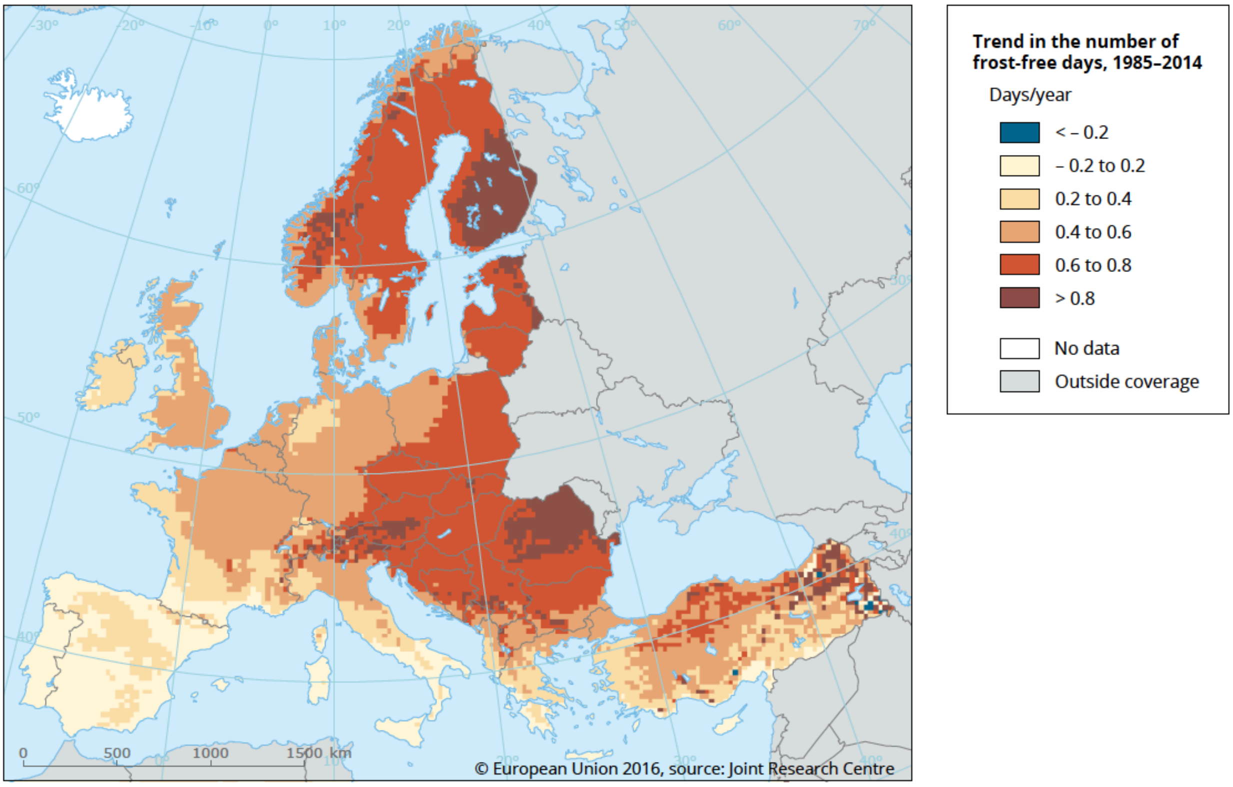
NB: the increase in CO_2 concentration being considered equal anywhere on earth, it is not part of the phenomena to describe locally (same for radiation).

1.3.5.1 ARABLE CROPS

Observed growing season

The thermal growing season is a basic agrological indicator for where and when crops can potentially be grown, assuming sufficient water, radiation and suitable soils. The duration of the growing season is for a large part of Europe defined by the duration of the period with **temperatures above a certain threshold**. The **duration of the frost-free season** is considered the period favourable for growth of many plant species (e.g. for flowering). However, active growth of plants requires higher temperatures, and for most of the temperate crops grown in Europe a **threshold temperature of 5 °C** can be used (EAA, 2012).

The thermal growing season of a number of agricultural crops in Europe has lengthened by **11.4 days** on average from 1992 to 2008. The delay in the end of the growing season was more pronounced than **the advance of its start**. The trend is not uniformly spread over Europe: the highest rates of change (larger than 0.8 days per year) were recorded along the Atlantic shores, in the British Isles, Denmark, central parts of Europe, central Italy, central and southern Spain, and in Turkey. There are also areas in Europe with an apparent trend for reductions in the frost-free period; however, these trends are not significant (EAA, 2012).



Source: MARS/STAT database ([98]).

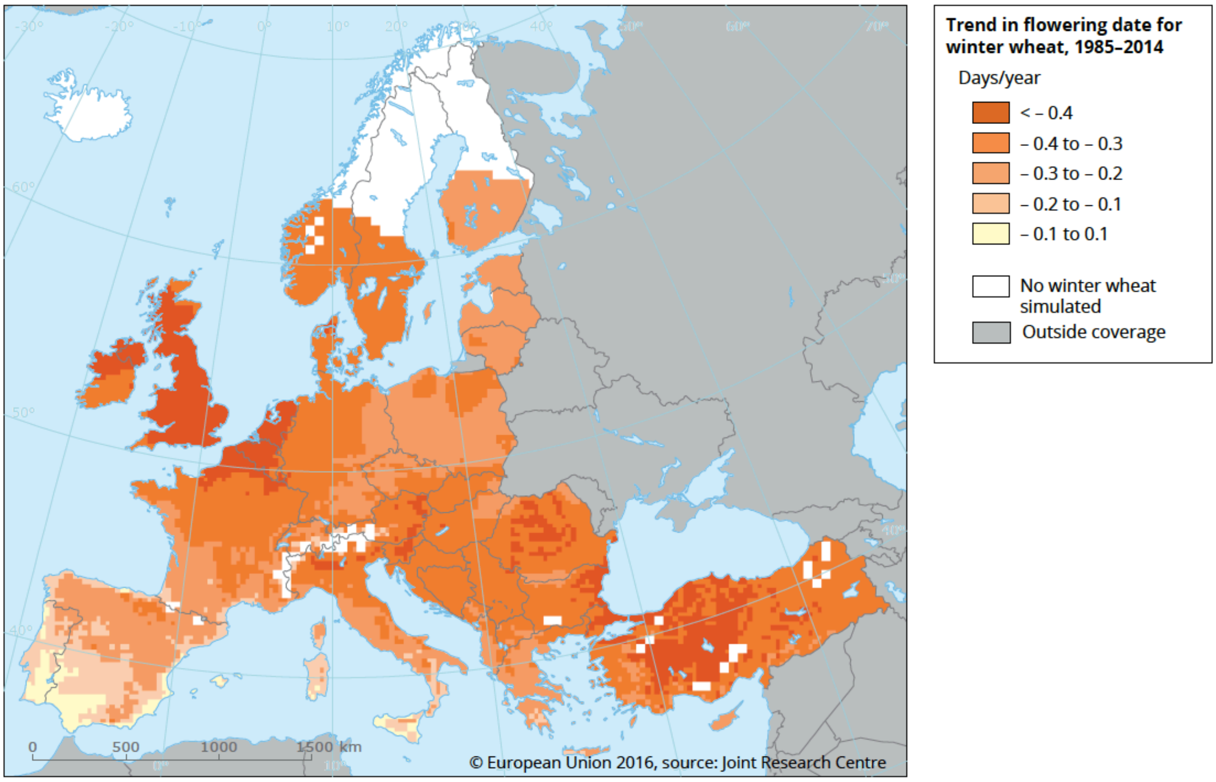
Figure 17: Trend in the number of frost-free days per year, 1985-2014 (EEA, 2016)

Observed agrophenology

Changes in crop phenology provide important **evidence of responses** to recent regional climate change. Although phonological changes are often influenced by management practices, in particular sowing date and choice of cultivar, **recent warming** in Europe has clearly advanced a significant part of the agricultural calendar. Specific stages of growth (e.g. flowering, grain filling) are particularly **sensitive to weather conditions** and critical for **final yield**. The timing of the crop cycle (agrophenology) determines the productive success of the crop. In general, a longer crop cycle is strongly correlated with higher yields, since a longer cycle permits better use of the available thermal energy, solar radiation and water resources.

Sowing or planting dates of several agricultural crops **have been advanced**, for example by 5 days for potatoes in Finland (1965–1999), 10 days for maize and sugar beet in Germany (1961–2000) and 20 days for maize in France (1974–2003) (EEA, 2012).

An analysis of the modelled flowering date for winter wheat in Europe between 1985 and 2014 shows a general and clear increasing trend, which is most pronounced in north-western Europe, the modelled flowering date has advanced by **two to four days/decade**. This modelled advance in flowering date probably exceeds what is observed in reality, as day length responses in the plants and farmers' choices of cultivars with longer growth duration will reduce this response.



Source: MARS/STAT database.

Figure 18: Trend in flowering date for winter wheat, 1985-2014 (EEA, 2016)

Observed water-limited crop productivity

Crop biomass production derives from the capture and conversion of solar energy through the process of photosynthesis. However, this process may be **restricted by low** (or high) **temperatures** or by **water limitations**. A simple index has been developed (EEA, 2012) by which the effective annual radiation for plant growth was estimated by **summing daily contributions of solar radiation on days with mean temperature above 5 °C, minimum temperature above 0 °C** and **sufficient soil water for supporting crop transpiration**. In practice the response depends on soil type that may have large differences in capacity for storing soil moisture and on possibilities for supplementary irrigation. Crop yield also depends on the timing of the crop growth and yield formation. **Yields in cereal and oilseed crops** respond particularly to the **duration of the grain filling period**. The impacts of unfavourable meteorological conditions and extreme events vary considerably, depending on the timing of **occurrence** and the development stage of the crops. Changes in the occurrence of **extreme events** such as **heat waves, droughts, heavy precipitation** and **floods** will greatly affect crop yield leading to increased variability and economic consequences (EEA, 2012).

A global analysis of **yields of cereal crops** (wheat, maize and barley) has shown **yield decreases** due to **increasing mean temperatures**. Similar effects have been observed for various countries in Europe. Increasing temperatures have also been attributed as one of the main causes for the **lack of yield increase** of winter wheat in France despite improvements in crop breeding. Grain yields in maize have been **steadily increasing in northern Europe**, whereas **yields in southern Europe** seem to have been **stagnating**. There is also a tendency for increasing variability of grain yields in France and Italy, linked to occurrence of heat waves and droughts. These climatic extremes affected the crop production in large areas of southern and central Europe in 2003 and 2007. In contrast to cereals and oilseed crops, **potato** and **sugar beet** seem to have responded **positively** to the **increasing temperatures** by increasing yields, most likely due to **longer growing seasons** (EEA, 2012).

Observed impacts

Climate change is likely to **increase cereal yields** in Northern Europe (medium confidence, disagreement) but **decrease yields** in Southern Europe (high confidence). In Northern Europe, climate change is very likely to extend the seasonal activity of pests and plant diseases (high confidence). Yields of some arable crop species like **wheat have been negatively affected** by observed warming in some European countries since the 1980s (medium confidence, limited evidence). Compared to AR4, new evidence regarding future yields in Northern Europe is less consistent regarding the magnitude and sign of change (IPCC, 2014).

During the 2003 and 2010 summer heat waves, grain-harvest losses reached **20 %** in affected regions of Europe. Cereals production fell on average by **40 %** in the Iberian Peninsula during the intense 2004/2005 drought (IPCC, 2014).

The summer 2003 heat wave and drought conditions, for example, caused significant damage to the agricultural sector in central and southern Europe through the reduction in production and losses of financial capital (see Figure 19).

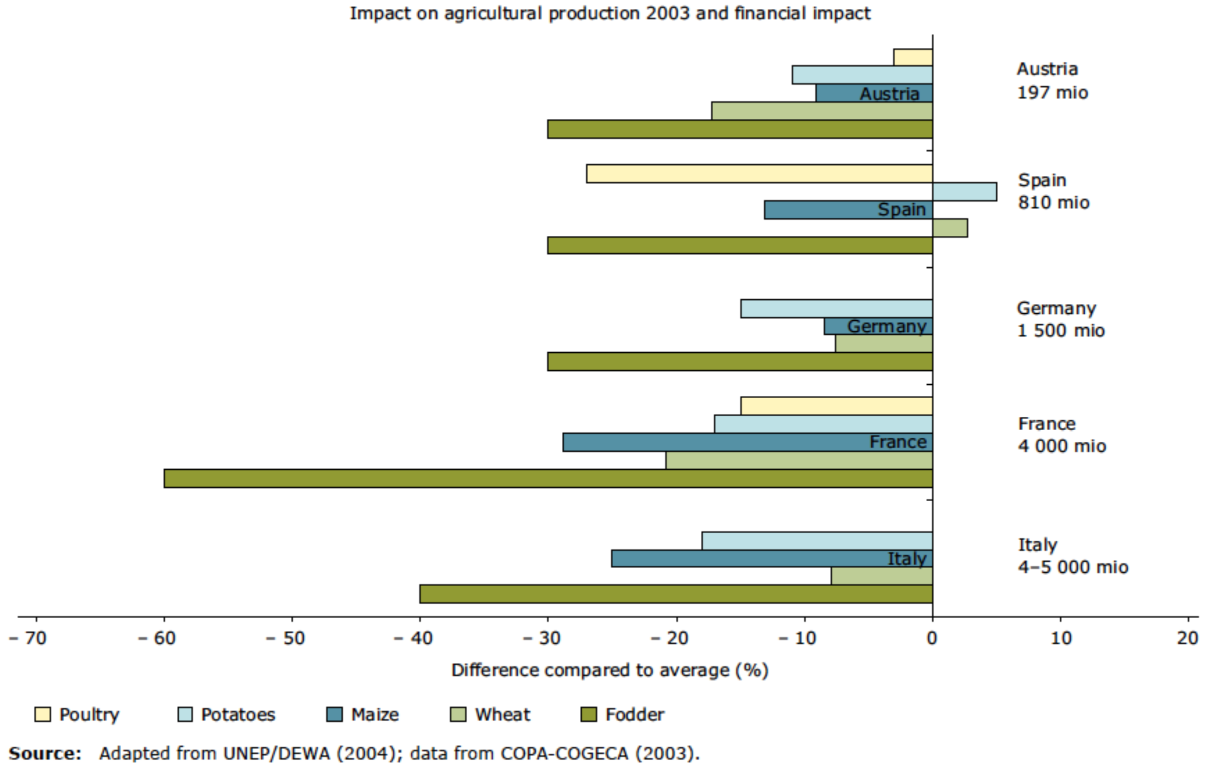


Figure 19: Impact of the summer 2003 heat wave and drought on agriculture in five countries (EEA, 2005)

Climate-induced variability in wheat production has increased in recent decades in **Southern and Central Europe** but no consistent reduction has been recorded in the northernmost areas of Europe. Country-scale rainfed cereals yields are below agro-climatic potentials, and wheat yield increases have levelled off in several countries over 1961–2009. **High temperatures and droughts during grain filling** have contributed to the **lack of yield increase of winter wheat** in France despite improvements in crop breeding. In contrast, in eastern Scotland, warming has favoured an increase in potato yields since 1960 (IPCC, 2014).

Projection for growing season

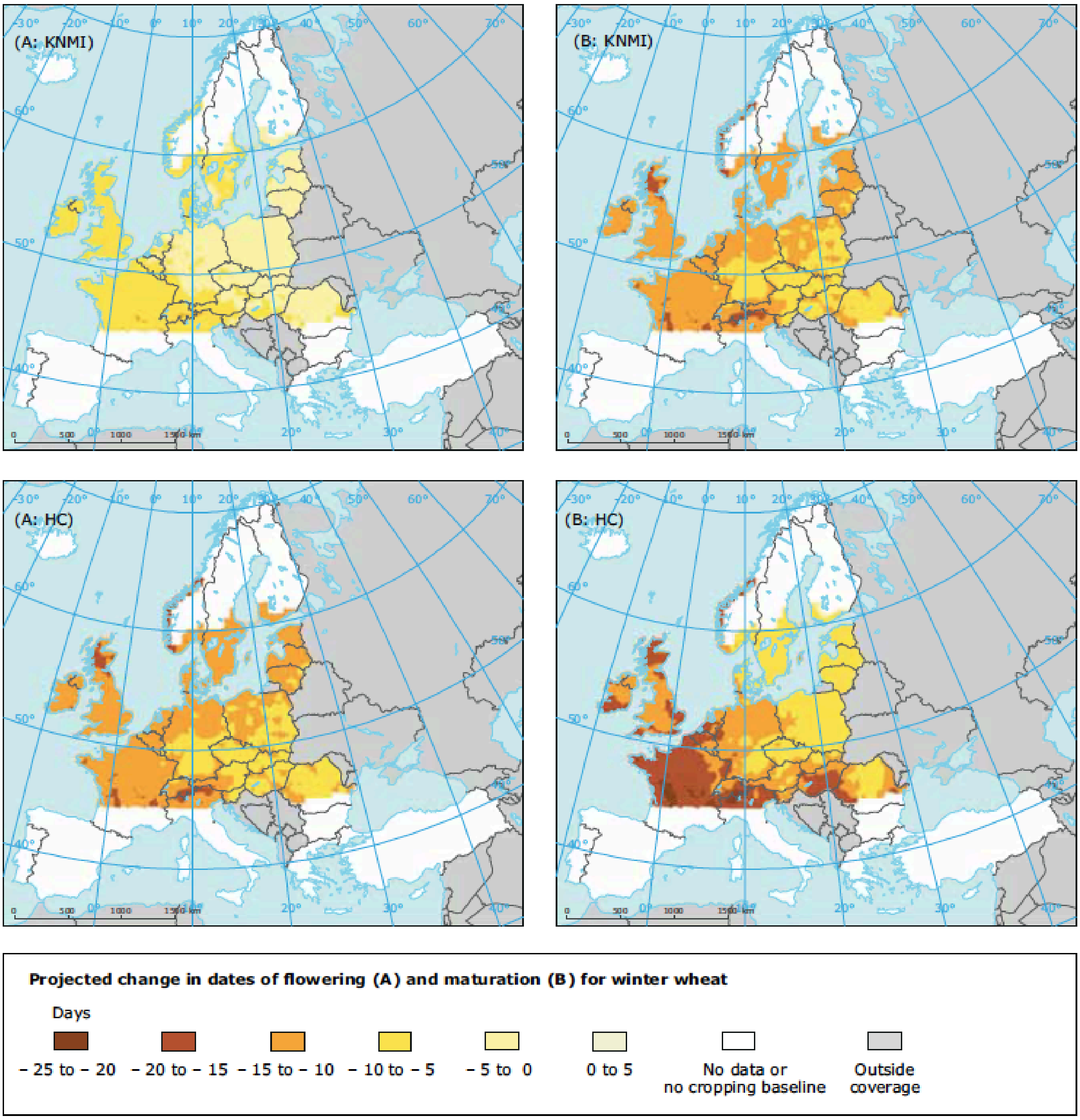
A warming of the climate is expected mainly to result in an **earlier start of the growing season** in spring and a longer duration in autumn. A longer growing season allows the **proliferation** of species that have optimal conditions for growth and development and can thus increase their productivity or number of generations (e.g. crop yield, insect population). This will in many cases also allow for introduction of new species previously unfavourable due to low temperatures or short growing seasons. This is relevant for **introduction of new crops**, but will also affect the **spreading of weeds, insect pests and diseases** (EAA, 2012).

A further lengthening of the growing season as well as a northward shift of species is projected as a result of the projected further increase in temperature across Europe. The date of **last frost** in spring is projected to advance by about **5 – 10 days by 2030** and by 10–15 days by 2050 throughout most of Europe (EEA, 2012). The suitability for growing certain crops will also depend on the **total amount of heat received** during the growing season expressed as a **temperature sum.** Projections show the greatest absolute increases in temperature sum in southern Europe, whereas relative changes are much larger in northern than in southern Europe (EEA, 2012).

The extension of the growing season is expected to be particularly beneficial in **northern Europe**, where **new crops could be cultivated** and where water availability is generally not restricting growth. In parts of the Mediterranean area the cultivation of some crops **may shift from the summer season** to the **winter season**, which could offset some of the negative impacts of heat waves and droughts during summer (Minguez et al., 2007). Other areas of Europe, such as **western France** and parts of **south-eastern Europe**, will experience yield reductions from hot and dry summers without the possibility of shifting the crop production into the winter seasons (EEA, 2012).

Projections for agrophenology

With the projected warming of the climate in Europe, further reductions in the **number of days required for flowering** in cereals **and maturity** may be expected throughout Europe. The modelled changes in flowering dates in Figure 20 include the expected effects of changes in cultivar choice on flowering and maturity dates. Since many plants (including cereals) in Europe require long days to flower, the effect of warming on date of flowering is smaller than would otherwise be expected. The flowering date **for winter wheat** is projected to show the greatest advance in **western parts of Europe**, but with a large uncertainty due to uncertainty in the underlying climate change projections. The advance in **maturity date** is larger than the advance in **flowering date**, leading to a shortening of the grain filling period, which will **negatively affect yields**. An independent study with a different phenology model and other climate change projections found similar advances in flowering date for winter wheat for England and Wales (14–16 days by 2050) (EEA, 2012).



Note: Model estimated mean change in dates of flowering and full maturation for winter wheat for the period 2031–2050 compared with 1975–1994 for the RACMO (KNMI) and HadRCM3 (Hadley Centre.HC) projections under the A1B emission scenario.

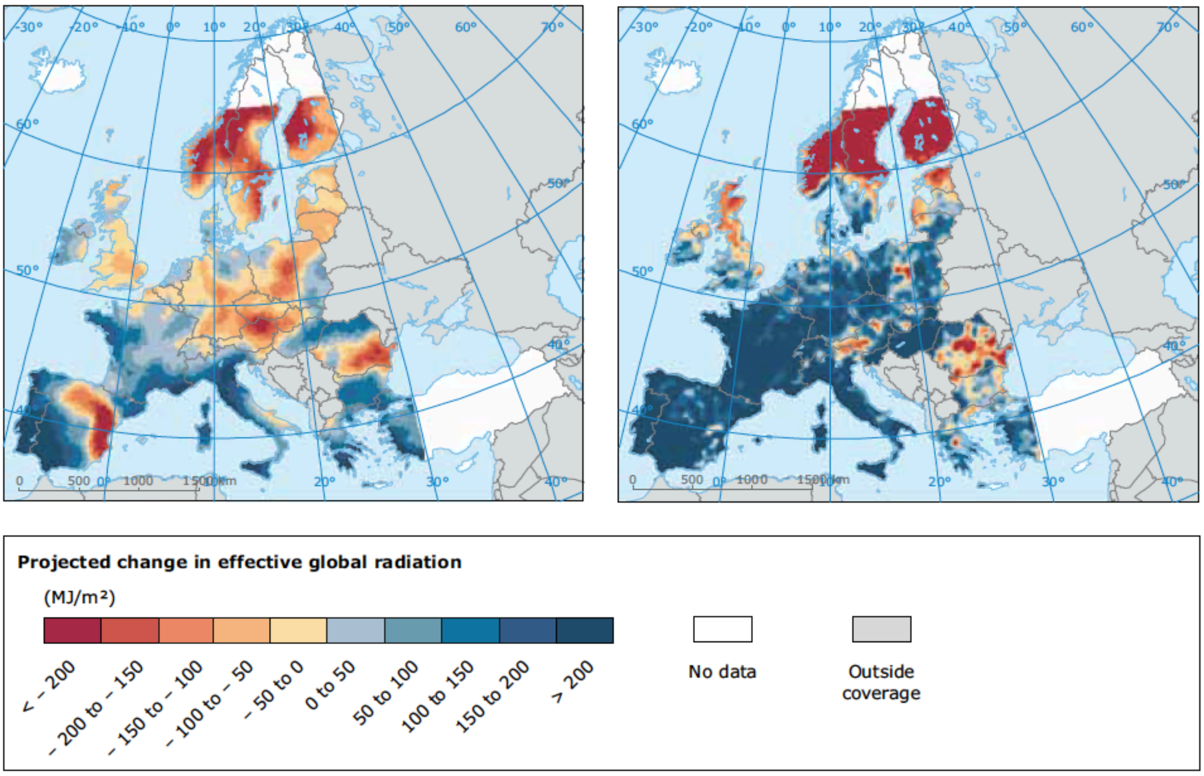
Source: Fels-Klerx et al., 2012.

Figure 20: Projected changes in flowering and maturation for winter wheat (EEA, 2012)

Projections for water-limited crop productivity

The impact of future changes in climate on crop yield depends on the characteristics of the climatic change within a region as well as on a combination of other environmental, economic, technological and management factors. The index of effective solar radiation sum has been developed as a proxy for the effects of environmental changes on crop productivity, and it integrates the daily solar radiation on those days where neither temperature nor soil moisture is limiting for growth. This index estimates the potential for rain-fed crop production using a standard soil across the entire continent, although this may be greatly modified by local soil conditions.

Figure 21 shows the projected changes in effective radiation sum for the 2040s for climate projections from two different climate models. Both projections show reduced production potential in large parts of **southern Europe** and increases in the **far north**, but they differ substantially for areas in-between. A broader analysis of climate change scenarios for agricultural productivity in Europe has provided a clear picture of **deterioration of agroclimatic conditions** from increased drought stress and a shortening of active growing season across **large parts of southern and central Europe**. Results also suggest a risk of an increasing number of unfavourable years for agricultural production in many European climatic zones, resulting in increased variability of crop yield from droughts and heat waves (EEA, 2012).

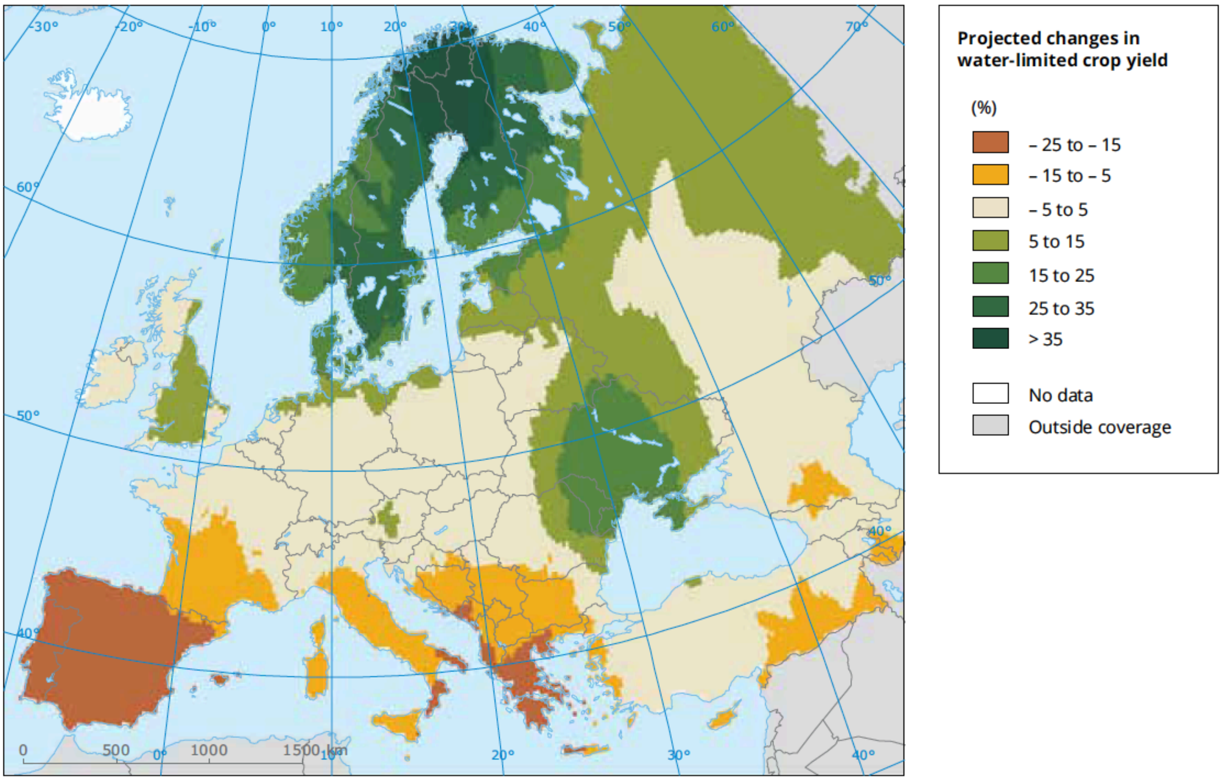


Note: Mean changes in effective solar radiation (MJ/m²), which is an indicator for water-limited crop productivity, for the period 2031–2050 compared with 1975–1994 for the RACMO (KNMI) and HadRCM3 (Hadley Centre.HC) projections under the A1B emission scenario.

Source: J.E. Olesen, 2012 (personal communication).

Figure 21: Projected changes in effective solar radiation from two climate models (EEA, 2012)

The estimates shown in Figure 21 do not consider the effects of enhanced atmospheric CO_2 levels on crop productivity. The ClimateCrop model was applied to explore the combined effects of projected changes in temperature, rainfall and CO_2 concentration across Europe, considering certain management changes thus incorporating effects of adaptation. The mean projected changes in Figure 22 show the same overall picture as Figure 21 of **decreases in yields** along the **Mediterranean** and **large increases in Scandinavia**. However, throughout large parts of western and central Europe mean changes in crop yields are likely to be small.



Note: The map shows the mean relative changes in water-limited crop yield simulated by the ClimateCrop model for the 2050s compared with the period 1961–1990 for 12 different climate model projections under the A1B emissions scenario. The simulation assumes that the irrigated area remains constant, and the results combine the response of the key crops wheat, maize and soybean, weighted by their current distribution.

Source: Adapted from Iglesias et al., 2012 and Ciscar et al., 2011.

Figure 22: Projected changes in water-limited crop yield (EAA, 2016)

Projected impacts

In the EU-27, a 2.5 °C regional temperature increase in the 2080s under the B2 scenario could lead to **small changes** (on average +3 %) in crop yields, whereas a 5.4 °C regional warming under the A2 scenario could reduce mean yields by **10 %** according to a study based on regional climate models. An initial benefit from the increasing CO_2 concentration for rainfed crop yields would contrast by the end of the century with yield declines in most European sub-regions, although wheat yield could increase under the A2 scenario. Disease-limited yields of rainfed wheat and maize in the 2030s does not show consistent trends across two GCMs. For a global temperature increase of 5 °C, agroclimatic indices show an increasing frequency of extremely unfavourable years in European cropping areas. Under the A2 and B2 scenarios, crop production shortfalls, defined as years with production below 50 % of its average climate normal production would double by 2020 and triple by 2070 as compared to a current frequency of 1 to 3 years per decade in the currently most productive southern European regions of Russia (IPCC, 2014).
The regional distribution of climate change impacts on agricultural production is likely to vary widely. **Southern Europe** would experience the **largest yield losses** (–25 % by 2080 under a 5.4 °C warming), with increased risks of rainfed summer crop failure. Warmer and drier conditions by 2050 would cause **moderate declines** in crop yields in **Central Europe** regions. In **Western Europe**, increased heat stress around flowering could cause considerable yield losses in wheat. For **Northern Europe**, there is diverging evidence concerning future impacts. Positive yield changes combined with the expansion of climatically suitable areas could lead to crop production increases (between 2.5 °C and 5.4 °C regional warming). However, increased climatic variability would **limit winter crops** expansion and cause at high latitudes high risk of marked cereal yield

loss. Spring crops from tropical origin like maize for silage could become cultivated in Finland by the end of the century (IPCC, 2014).
Cereal yield reduction from ozone could reach **6 and 10 %** in 2030 for the European Union with the B1 and A2 scenarios, respectively. Because of limited land availability and soil fertility outside of Chernozem (black soil) areas, the shift of agriculture to the boreal forest zone would not compensate for crop losses owing to increasing aridity in South European regions of Russia with the best soils (IPCC, 2014).
With generally warmer and drier conditions, **deep rooted weeds** and **weeds** with contrasting physiology, such as C4 species, could pose a more serious threat to crops than shallow rooted C3 weeds (IPCC, 2014).
Arthropod-borne diseases (viruses and phytoplasmas), winter infection root and stem diseases (phoma stem canker of oilseed rape and eyespot of wheat), Fusarium blight could create **increasing damages in Europe** under climate change. However, other pathogens such as cereal stem rots (e.g., Puccinia striiformis) could **be limited** by increasing temperatures (IPCC, 2014).
Increased damages from plant pathogens and insect pests are projected by 2050 in **Nordic** countries, which have hitherto been protected by cold winters and geographic isolation. Some pests, such as the European **corn borer**, could also extend their climate niche in Central Europe (IPCC, 2014).

Table 2: Projected regional impacts on arable crops (IPCC, 2014)

Region	Sub-region	Yield impacts (%)	Scenario	Reference
Europe	Boreal	Wheat, maize, soybean: +34 to +54	A2, B2 2080 HadCM3/HIRHAM, ECHAM4/RCA3	Iglesias et al. (2012)
	Alpine	Wheat, maize, soybean: +20 to +23		
	Atlantic North	Wheat, maize, soybean: –5 to +22		
	Atlantic Central	Wheat, maize, soybean: +5 to +19		
	Atlantic South	Wheat, maize, soybean: –26 to –7		
	Continental North	Wheat, maize, soybean: –8 to +4		
	Continental South	Wheat, maize, soybean: +11 to +33		
	Mediterranean North	Wheat, maize, soybean: –22 to 0		
	Mediterranean South	Wheat, maize, soybean: –27 to +5		

AVEMAC Project

Regarding the AVEMAC Project (JRC, 2012), impacts for the main crops in Europe have been simulated under two realizations (warmest and coldest realizations of the A1B scenario) for the time horizons 2020 and 2030 (not considering adaptations measures).

For maize, estimates of the warm scenario for 2030 indicated in the whole EU a potential decrease of about **9 % in the production** of grain maize in comparison to the 2000 baseline. The decrease would affect **36 NUTS2 regions**. These regions are mainly located in important countries for grain maize production such as **France, Romania, Italy, Hungary and Spain** and are mostly characterised by cereal and mixed farming systems. An opposite situation is foreseen by the cold scenario with a potential increase of the EU overall production of grain maize both in 2020 and 2030 compared to the baseline. Many regions in Italy, Spain, Romania and Greece are expected to have an increase of production, in some cases quite important (+15-20 %). The cold scenario foresees a stable production in France.

Regarding **sunflower**, the analysis of the warm scenario for 2030 indicates a potential decrease in sunflower production of around **10 %** for all important **Spanish production regions**. Potential decreases in sunflower production are estimated for **France**, too, however with a smaller decrease from **4 % to 8 % depending on the region**. All regions in **Hungary** and almost all regions in **Bulgaria** and **Romania** are estimated to be potentially affected by a significant decrease in 2030. At country level resulting figures show a potential decrease of 14 % for

Romania, 12 % for Hungary, and 13 % for Bulgaria. The analysis for the cold scenario anticipates to 2020 the variations foreseen in the warm scenario in 2030 for all most important Spanish regions producing sunflower. The 2030 cold scenario almost reflects the results obtained with the warm scenario at least for what concerns the identification of the NUTS2 regions where a significant potential decrease in production can be expected (in Spain, Hungary, Bulgaria and Romania). Different results are obtained for French regions, which seem not to be concerned by a potential diminution of the production in the cold scenario.

For **wheat**, according to the warm scenario in 2030, regions in **Northern France**, **Poland, Lithuania** and **Latvia** could be affected by a potential **decrease** in the order of **8 % to 18 %** that can be considered significant. Regions potentially affected have a dominance of cereal and mixed farming systems. In France some regions that are also potentially affected are characterized by a diverse pattern of farming systems with a relatively high share of dairy farms. On the other hand, analysis results for regions in **Italy, Bulgaria**, and **Spain** indicate a significant potential **increase in wheat production**. These regions are characterised by a dominance of cereal and mixed farming systems. While the "warm scenario" does not foresee any significant decrease of production in 2020, the analysis for the "cold scenario" highlights several NUTS2 regions (mainly in **Spain** and **Poland**) that may be potentially affected by a significant **decrease of wheat production**. On the contrary some Regions in Northern and Western France should register a statistically significant potential increase. The cold scenario for 2030 confirms a significant potential decrease of production in numerous Polish regions. Not expected with the warm scenario, all Romanian, northern Bulgarian and western Hungarian regions will be potentially affected by a significant decrease of production according to the cold scenario.

For **rapeseed**, according to the results of the analysis for the warm scenario, only regions in **France** are estimated to experience a significant potential **decrease by 2030 of -11 % to – 18 %**, depending on the region. The same regions would have a slightly positive potential increase, even if not significant, when taking into account the cold scenario. These regions are characterized by a prevalence of cereal and mixed farming systems. The analysis for the cold scenario shows some significant potential increase in 2020 only in a few NUTS2 regions located in Northern Germany, Denmark and Poland; most of these variations become insignificant in 2030.

Bioenergy cultivation

Climate change will **affect bioenergy cultivation** patterns in Europe by **shifting northward** their potential area of production (medium confidence). Elevated atmospheric carbon dioxide (CO_2) can improve drought tolerance of bioenergy crop species due to improved plant water use, maintaining high yields in future climate scenarios in temperate regions (low confidence) (IPCC, 2014).

The potential distribution of temperate oilseeds (e.g., oilseed rape, sunflower), starch crops (e.g., potatoes), cereals (e.g., barley), and solid biofuel crops (e.g., sorghum, Miscanthus) is projected to **increase in Northern Europe** by the 2080s, as a result of increasing temperatures, and to **decrease in Southern Europe** due to increased drought frequency. Mediterranean oil and solid biofuel crops, currently restricted to Southern Europe, are likely to extend further north. The physiological responses of bioenergy crops, in particular C3 Salicaceae trees, to rising atmospheric CO_2 concentration may increase drought tolerance because of improved plant water use; consequently yields in temperate environments may remain high in future climate scenarios (IPCC, 2014).

A future increase in the northward extension of the area for **short rotation coppice** (SRC) cultivation leading to GHG neutrality is expected. However, the northward expansion of SRC would erode the European terrestrial carbon sink due to intensive management and high turnover of SRC compared to conventional forest where usually harvesting is less than annual growth (IPCC, 2014).

1.3.5.2 PERMANENT CROPS

Observed impacts

Earlier flowering and maturity have been observed (robust evidence, high agreement) worldwide in **grapes and apples** (IPCC, 2014).

Changes in the phenological phases of several perennial crops in Europe, such as the **advance in the start of the growing season of fruit trees (2.3 days / 10 years)**, cherry tree blossom (2.0 days / 10 years) and apple tree blossom (2.2 days / 10 years), in line with increases of up to 1.4 °C in mean annual air temperature have been observed in Germany during 1961–2000 (EAA, 2012).

Wine production in Europe accounts for more than 60 % of the global total and makes an important contribution to cultural identity. In northeast Spain, **grape yield** was reduced by an increased water deficit in the reproductive stages since the 1960s (IPCC, 2014).

Projected impacts

For perennial crops, **winter chill accumulation** that is important to many fruit and nut trees is projected to continue its decline. Reductions in suitability for grapevine are expected in most of the wine-producing regions. **Wine grape production and quality** will be affected in Europe, USA, Australia (IPCC, 2014).
Climate change will **change the geographic distribution** of **wine grape** varieties (high confidence) and this will reduce the value of wine products and the livelihoods of local wine communities in **Southern** and **Continental Europe** (medium confidence) and **increase production** in Northern Europe (low confidence) (IPCC, 2014).
Apart from **impacts on grapevine yield**, higher temperatures are also expected to **affect wine quality** in some regions and grape varieties by changing the ratio between sugar and acids. In **Western and Central Europe**, projected future changes could benefit wine quality, but might also demarcate new potential areas for viticulture (IPCC, 2014).
Arthropod-borne diseases (viruses and phytoplasmas), grapevine moth, and a black rot fungus in fruit trees could create **increasing damages in Europe** under climate change. However, other pathogens such as grapevine powdery mildew could **be limited** by increasing temperatures (IPCC, 2014).

Grapevine phenology in 2020 and 2050

Considering the AVEMAC Project (JRC, 2012), grapevine growth and development is largely driven by temperature. Changes in maturity and flowering date comparing projections in 2020 and 2050 with respect to 2000 are observed. Three varieties with different maturity cycles are tested: Syrah, Chardonnay (early maturity), and Cabernet Sauvignon (late maturity). A generalized **anticipation of maturity dates** is projected for **most of the areas of Europe**. However, in some areas of Southern Europe, where projected temperatures above an optimum become more frequent in 2050, the average rate of growth decreases and maturity is delayed. The protected designation of origin for wines is related to the peculiar combination of different factors into specific geographical areas (terroir): environment (soil and climate), varieties, and knowledge on agricultural and oenological practices. These projections indicate several changes to the current situation. Indeed, producers and consumers have already experienced changes in some wines, for instance in relation to alcohol content. Qualitative aspects of vines are tightly related to the concept of terroir, hence related to the matching of grapes to an articulated set of conditions. Consequently, the analysis projects a **large potential vulnerability of vine production and quality**.

1.3.5.3 LIVESTOCK PRODUCTION

Effects on livestock are mostly **indirect** through feed production (changes in productivity of pastures and forage crop); there is **little direct evidence** of climate change effects on livestock, except for changes in livestock diseases related to climate change (EEA, 2012).

Observed direct impacts

Climate change can lead to significant shifts in the geographic and seasonal distribution ranges of vector-borne diseases in Europe. Climate can affect vector-borne diseases by shortening the life-cycles of vectors and the incubation periods of vector-borne pathogens, thereby potentially leading to larger vector populations and higher transmission risks. Over the longer term, seasonal changes could affect both vectors and host animals, as well as human behaviours and land-use patterns, thereby further influencing the geographical distribution, seasonal activity and overall prevalence of vector‑ borne diseases in Europe (EEA, 2012).

Climate change has contributed to **vector-borne disease in ruminants** in Europe (high confidence) and **northward expansion of tick disease vectors** (medium confidence). The spread of **bluetongue virus in sheep** across Europe has been partly attributed to climate change through increased seasonal activity of the Culicoides vector. The distribution of this vector is unlikely to expand but its abundance could increase in **Southern Europe**.

Ticks, the primary arthropod vectors of zoonotic diseases in Europe (e.g., Lyme disease and tick-borne encephalitis), have changed distributions towards **higher altitudes and latitudes** with climate change. Exposure to fly strike could increase in a warmer climate but adaptation in husbandry practices would limit impacts on livestock. The overall risk of incursion of Crimean-Congo hemorrhagic fever virus in livestock through infected ticks introduced by migratory bird species would not be increased by climate change. The probability of introduction and large-scale spread of Rift Valley fever in Europe is also very low (IPCC, 2014).

Table 3: Projected regional impacts on Livestock

Regional impacts on livestock

Region	Sub-region	Climate change impacts	Scenarios	Reference
Europe	Netherlands	Dairy production affected at daily mean temperatures above 18°C		Section 23.4.2
	Italy	Mortality risk to dairy cattle increased by 60% by exposure to high air temperature and high air humidity during breeding.		
	French Uplands	Annual grassland production system significantly reduced by 4-year exposure to climatic conditions.	A2 2070	Cantarel et al. (2013)
	France	No impact on dairy yields.	A2 1970–1999, 2020–2049, 2070–2099 ARPEGE	Graux et al. (2011)
	Ireland, France	Grassland dairy system increases potential of dairy production, with increased risk of summer–autumn forage failure in France.	A1B By the end of century	
	Overall Europe	Spread of bluetongue virus (BTV) in sheep and ticks in cattle due to climate warming.	2080	Graux et al. (2011)
		No increase in risk of incursion of Crimean–Congo hemorrhagic fever virus in livestock.		Section 23.4.2

Livestock production is adversely affected **by heat**. With intensive systems, heat stress reduced **dairy production** and growth performance of large **finishing pigs** at daily mean air temperatures above 18 °C and 21 °C, respectively. High temperature and air humidity during breeding increased cattle mortality risk by 60 % in Italy. Climate change may adversely affect **dairy production in Southern Europe** because of heat stress in lactating cows (medium confidence) (IPCC, 2014).

Exposure to a high temperature–humidity index can effect milk production and quality, mortality, reproductive health and disease susceptibility, especially in intensive dairy cattle (EEA, 2016).

Projected indirect impacts

As they are reliant on crop and grass yields and quality, livestock production systems are highly exposed to the impacts of climate change at local (grazing and home-grown forage) and global (feed concentrate imports) levels (EEA, 2016).

With grass-based livestock systems, model simulations (A1B scenario, ensemble of downscaled GCMs) show by the end of the 21st century increases in potential dairy production in Ireland and France, with, however, **higher risks of summer-autumn** production failures in **Central Europe** and at French sites. Climate conditions projected for the 2070s in central France (A2 scenario) reduced significantly grassland production in a 4-year experiment under elevated CO_2. At the same site, a single experimental summer drought altered production during the next 2 years (IPCC, 2014).

Resilience of grassland vegetation structure was observed to prolonged experimental heating and water manipulation. However, weed pressure from tap-rooted forbs was increased after severe experimental summer droughts. Mediterranean populations could be used to breed more resilient and better-adapted forage plant material for livestock production (IPCC, 2014).

Table 4 demonstrates that climate change presents very different challenges depending on whether intensive livestock systems or extensive (grass-based) livestock systems that are addressed (EEA, 2016).

Table 4: Illustration of challenges and adaptation solutions to climate change impacts on European livestock systems (EEA, 2016)

Climate effect	Intensified livestock systems (high inputs and outputs, reduced or zero grazing)		Wide-value systems (grazing, low inputs, systemic diversity)	
	Features and challenges	Adaptations	Features and challenges	Adaptations
Increased temperatures and temperature extremes (especially in southern Europe)	Housed animals are protected from extremes, but higher productivity animals are more susceptible to heat stress; extra heat is also produced from animals being in close proximity	Improve ventilation and housing conditions; genetic approaches for breeds that have better resilience against heat stress	Grazing animals are exposed to temperature extremes, but lower productivity animals are more resilient to heat stress; droughts will have effects on pasture productivity	Provision of shaded areas in pasture; trees for shade can also improve the resilience of swards to extremes; genetic approaches for breeds that have better resilience against heat stress
Spread and increased incidence of pathogens and pathogen vectors	Housed animals avoid many pathogens, but large numbers of animals kept in close proximity to each other increases potential hazards	Use of antibiotics (but limited by increasing resistance); new medical interventions, including use of feeds and supplements; monitoring of health status; genetic approaches for resilient breeds	Grazing animals expected to be more susceptible to liver-fluke and other pathogens under climate change (increased risk), but smaller herd sizes and more diversity reduce hazards	Use of antibiotics (limited by resistance); new medical interventions; monitoring of health status; genetic approaches for resilient breeds; land management to reduce pathogen impact
Increased crop and grass productivity; changes in nutritional quality	It is possible to identify and import feeds for the most efficient dietary mix and control diets on an individual basis, but changes in nutritional quality need to be explored	Improve efficiency of nutrient uptake from feed and make predictions of impacts of changes on nutritional quality; identification of best crops and management approaches in different conditions	Increased pasture and meadow productivity can improve livestock productivity and improve the productivity of home-grown feed crops, but quality may vary	Improve efficiency of nutrient uptake from feed and make predictions of impacts of changes on nutritional quality; identification of new grazing management approaches and supplementary feeds
Increased pressure on water supplies	Intensive systems use large amounts of water, increasing use of feed concentrates increases water demand	More efficient collection, storage and transport of water; regulation to minimise water demand; improve water governance	Provision of water in the field may be difficult and inefficient; drought may reduce grassland productivity	Provision of shade can reduce water demand; more efficient storage and transport of water; improve water governance
Increased variability in crop and grass yields	Reliance on imported feeds brings vulnerability to price increases; de-coupling from local feed production reduces impacts of local climate; increased rainfall increases soil compaction from harvesting grasslands	Use of home-grown protein crops; increase diversity in feed crops grown; control traffic operations to restrict soil compaction	Variability in local conditions can negatively affect grass growth and fodder crops for home-grown feeds, but systems are robust to changes in global feed prices; increased rainfall may reduce land availability for grazing	Improve systems (use of legumes in mixed swards, agroforestry) and management to increase sward resilience to extreme conditions; restrict grazing during very wet periods

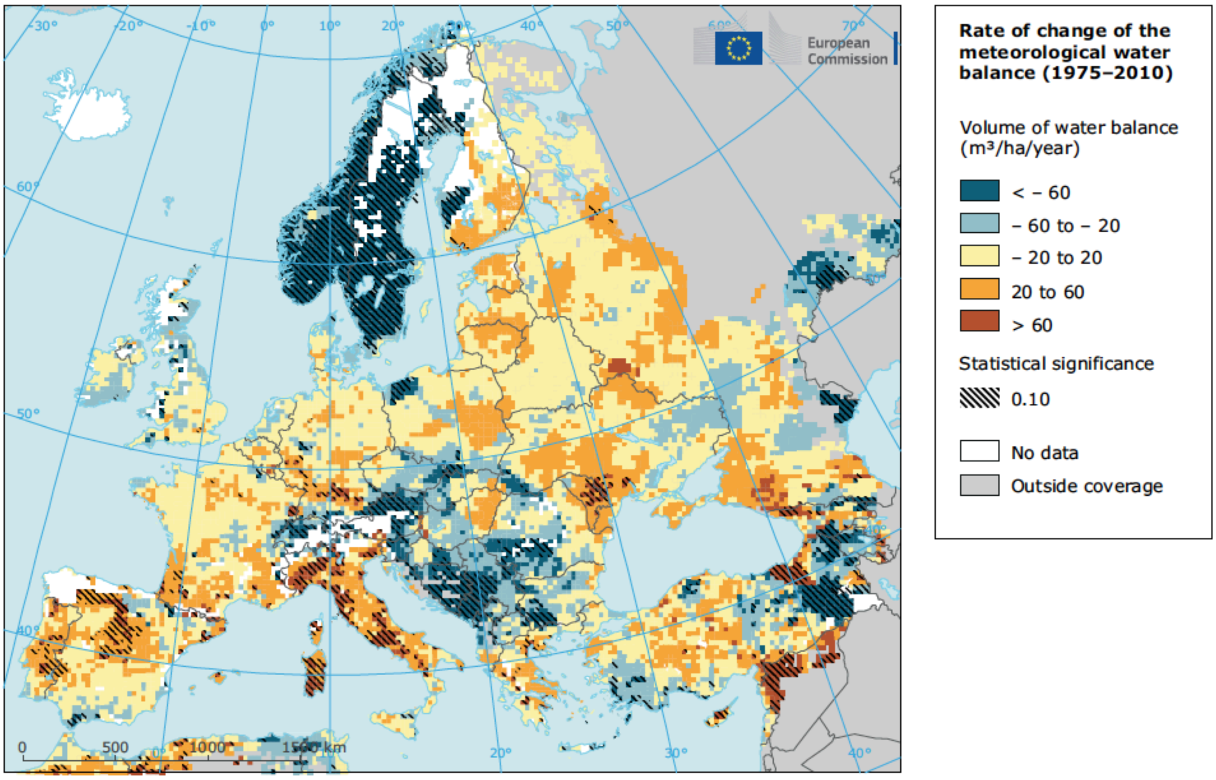
Source: ETC-CCA.

1.3.6 Water resources and agriculture

Observed situation

Water is essential for plant growth and there is a relationship between plant biomass production and transpiration, with the water-use efficiency (biomass production per unit water transpired) being affected by crop species as well as management. Increasing atmospheric CO_2 concentration will lead to higher water use efficiency through reductions in plant transpiration and increased photosynthesis. Higher temperatures and lower relative humidity leads to higher evaporative demands, which reduces the water-use efficiency. The resulting effect of climate change on water-use efficiency is therefore a combination of changes in temperature and atmospheric CO_2 concentration as well as changes in crop choice and management. The water demand by crops must be met through rainfall during the growing period, from soil water storage or by irrigation. In drought prone areas, increasing demands for water by industrial and urban users intensify the **competition for water for irrigation** in agriculture (EEA, 2012).

Figure 23 estimates the change in the water balance, which is the difference between a reference evapotranspiration and the rainfall. This indicator provides only a rough proxy for changes in irrigation demand, because actual irrigation demand is determined by the crops grown, the type of irrigation applied and the local soil conditions. In the period considered (1975–2010), the Iberian Peninsula and Italy experienced an increase in the volume of water required for irrigation, if yields of irrigated crops were to be maintained, whereas parts of south-eastern Europe have experienced a decrease (EEA, 2012).



Note: The map provides an estimate of the increase (brown in map) or decrease (blue in map) of the water volume required for irrigation assuming that all other factors are unchanged and given that there is an irrigation demand.

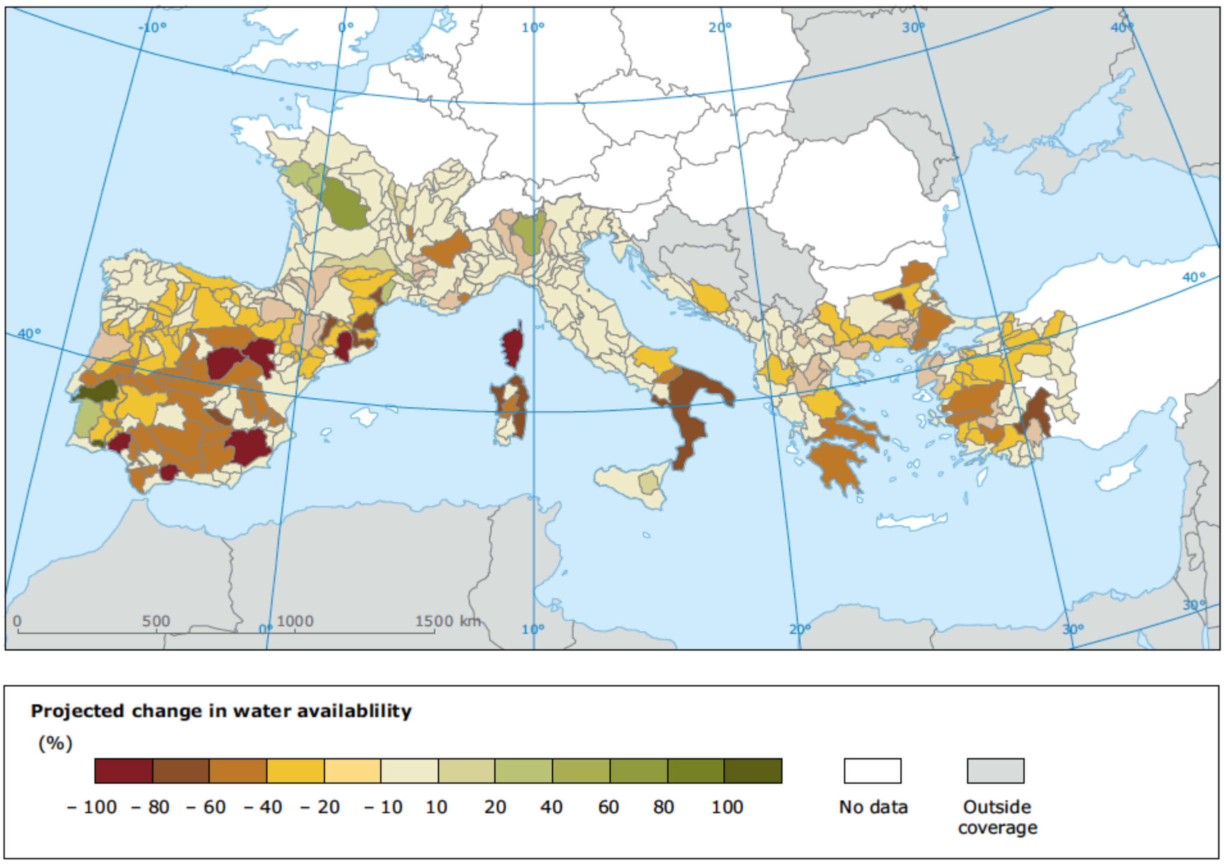
Source: MARS/STAT database.

Figure 23: Rate of the meteorological water balance for the period 1975-2000 (EEA, 2012)

Projected situation

Climate change will **increase irrigation needs** (high confidence) but future irrigation will be constrained by reduced runoff, demand from other sectors, and by economic costs. By the 2050s, **irrigation will not be sufficient** to prevent **damage from heat waves** to crops in some sub-regions (medium confidence). System costs will increase under all climate scenarios (high confidence). Integrated management of water, also across countries' boundaries, is needed to address future competing demands among agriculture, energy, conservation, and human settlements (IPCC, 2014).

As a result of increased **evaporative demand**, climate change is likely to significantly reduce **water availability** from river abstraction and **from groundwater resources** (medium confidence), in the context of increased demand (from agriculture, energy and industry, and domestic use) and cross-sectoral implications that are not fully understood (IPCC, 2014).
The expected increasing **evapotranspiration** will put pressure on the use of irrigation in drought-prone areas. Irrigation in Europe is currently concentrated along the **Mediterranean**, where some countries use more than 80 % of total freshwater abstraction for agricultural purposes. The increasing demand for irrigation will therefore increase the competition for water, in particular where total water availability declines due to reduced precipitation. Assuming that **urban water demands** would have preference over agricultural purposes, the proportional reduction of **water availability for irrigation** in many European basins is larger than the reduction in annual run-off (Figure 24). Projections for the **Mediterranean region** show a considerable **decline** in water availability, which in some areas makes current irrigation practices impossible in the future (EEA, 2012).



Note: Relative change in water availability for irrigation as projected under the A1B emission scenario by the HIRHAM (DMI) regional climate model for 2071–2100 relative to 1961–1990.

Source: Iglesias et al., 2012.

Figure 24: Projected change in water availability for irrigation in the Mediterranean region by 2071-2100 (EEA, 2012)

Future projected trends confirm the widening of water resource differences between Northern and Southern Europe reported in AR4. In Southern Europe, **soil water content will decline**, saturation conditions and drainage will be increasingly rare and **restricted to periods in winter and spring**, and snow accumulation and melting will change, especially in the mid-mountain areas (IPCC, 2014).

Across most of **Northern** and **Continental Europe**, an increase in **flood hazards** could increase damages to crops and plant growth, complicate soil workability, and increase yield variability (IPCC, 2014).

Groundwater recharge and/or water table level would be significantly **reduced** by the end of the 21st century under A2 scenario for river basins located in southern Italy, Spain, northern France, and Belgium. However, nonsignificant impacts were found for aquifers in Switzerland and in England. Less precipitation in summer and higher rainfall during winter could increase nitrate leaching with negative impacts on water quality. Even with reduced nitrogen fertilizer application, groundwater nitrate concentrations would increase by the end of the century in the Seine river basin. More robust water management, pricing, and recycling policies to secure adequate future water supply and prevent tensions among users could be required in Southern Europe (IPCC, 2014).

Reduced suitability for rainfed agricultural production will increase water demand for crop irrigation. However, increased irrigation may **not be a viable option**, especially in the **Mediterranean area**, because of projected declines in total runoff and groundwater resources. In a number of catchments water resources are already over-licensed and/or overabstracted and their reliability is threatened by climate change-induced decline in groundwater recharge and to a lesser extent by the increase in potential demand for irrigation. To match this demand, irrigation **system costs could increase by 20 to 27 %** in southern Italy and new irrigation infrastructures would be required in some regions. However, **since the economic benefits** are expected to be small, the adoption of irrigation would require changes in institutional and market conditions. Moreover, since aquatic and terrestrial ecosystems are affected by agricultural water use, irrigation demand restrictions are projected in environmentally focussed future regional scenarios (IPCC, 2014).

1.4 SYNTHESIS FOR EUROPE

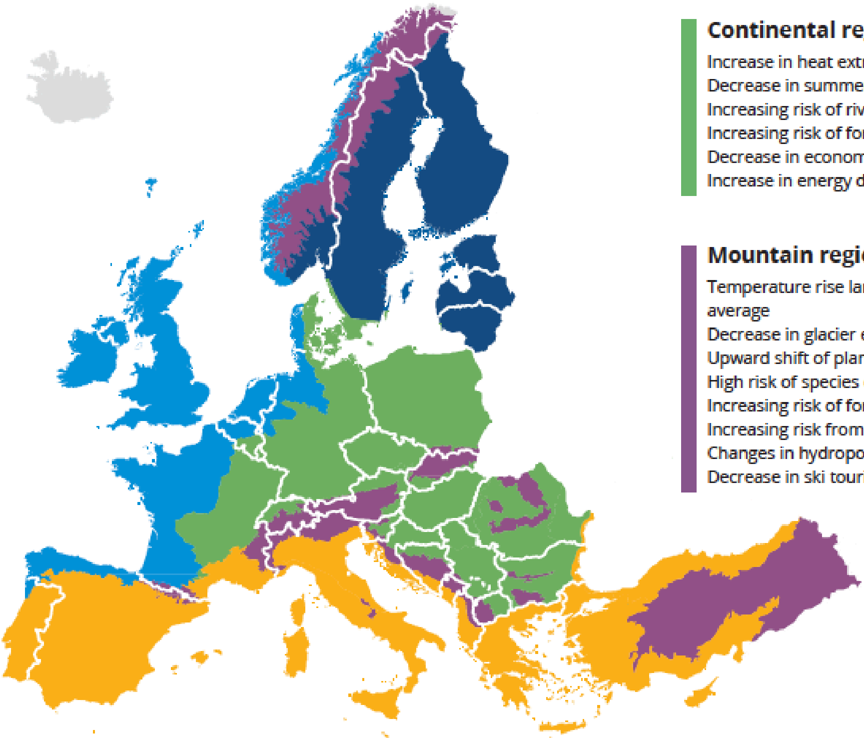
1.4.1 Key observed and projected impacts

Atlantic region
- Increase in heavy precipitation events
- Increase in river flow
- Increasing risk of river and coastal flooding
- Increasing damage risk from winter storms
- Decrease in energy demand for heating
- Increase in multiple climatic hazards

Arctic region
- Temperature rise much larger than global average
- Decrease in Arctic sea ice coverage
- Decrease in Greenland ice sheet
- Decrease in permafrost areas
- Increasing risk of biodiversity loss
- Some new opportunities for the exploitation of natural resources and for sea transportation
- Risks to the livelihoods of indigenous peoples

Boreal region
- Increase in heavy precipitation events
- Decrease in snow, lake and river ice cover
- Increase in precipitation and river flows
- Increasing potential for forest growth and increasing risk of forest pests
- Increasing damage risk from winter storms
- Increase in crop yields
- Decrease in energy demand for heating
- Increase in hydropower potential
- Increase in summer tourism

Continental region
- Increase in heat extremes
- Decrease in summer precipitation
- Increasing risk of river floods
- Increasing risk of forest fires
- Decrease in economic value of forests
- Increase in energy demand for cooling



Mountain regions
- Temperature rise larger than European average
- Decrease in glacier extent and volume
- Upward shift of plant and animal species
- High risk of species extinctions
- Increasing risk of forest pests
- Increasing risk from rock falls and landslides
- Changes in hydropower potential
- Decrease in ski tourism

Coastal zones and regional seas
- Sea level rise
- Increase in sea surface temperatures
- Increase in ocean acidity
- Northward migration of marine species
- Risks and some opportunities for fisheries
- Changes in phytoplankton communities
- Increasing number of marine dead zones
- Increasing risk of water-borne diseases

Mediterranean region
- Large increase in heat extremes
- Decrease in precipitation and river flow
- Increasing risk of droughts
- Increasing risk of biodiversity loss
- Increasing risk of forest fires
- Increased competition between different water users
- Increasing water demand for agriculture
- Decrease in crop yields
- Increasing risks for livestock production
- Increase in mortality from heat waves
- Expansion of habitats for southern disease vectors
- Decreasing potential for energy production
- Increase in energy demand for cooling
- Decrease in summer tourism and potential increase in other seasons
- Increase in multiple climatic hazards
- Most economic sectors negatively affected
- High vulnerability to spillover effects of climate change from outside Europe

Figure 25: Key observed and projected climate and impacts for the main regions in Europe (EAA, 2016)

Table 5: Observed and projected climate change and impacts for the agricultural sector (EEA, 2012)

	What is already happening	What could happen
Climate impacts on socio-economic systems and human health		
Agriculture		
Growing season for agricultural crops (C)	The thermal growing season of a number of agricultural crops in Europe has lengthened by 11.4 days on average from 1992 to 2008. The delay in the end of the growing season was more pronounced than the advance of its start.	The growing season is projected to increase further throughout most of Europe which would allow a northward expansion of warm-season crops to areas that are currently not suitable.
Agrophenology (C)	Flowering of several perennial crops has advanced by about two days per decade in recent decades. These changes are affecting crop production and the relative performance of different crop species and varieties.	The shortening of crop growth phases in many crops is expected to continue. The shortening of the grain filling phase of cereals and oilseed crops can be particularly detrimental to yield.
Water-limited crop productivity (N)	Yields of several crops (e.g. wheat) are stagnating and yields of other crops (e.g. maize in northern Europe) are increasing, partly due to climate change. Extreme climatic events, including droughts and heat waves, have negatively affected crop productivity during the first decade of the 21st century.	Future climate change can lead to yield decreases or increases, depending on crop type and with considerable regional differences across Europe. Yield variability is expected to further increase under projected future climate change (including increased intensity and frequency of extreme events).
Irrigation water requirement (C)	In Italy and the Iberian Peninsula, an increase in the volume of water required for irrigation from 1975 to 2010 has been estimated, whereas parts of south-eastern Europe have recorded a decrease.	In southern Europe suitability for rain-fed agriculture is projected to decrease and irrigation requirements are projected to increase under future climate change.

Table 6: Key observed and projected climate change and impacts for the main regions in Europe (EEA, 2016)

Direction of observed and projected climate change and impacts for the main regions in Europe													
Section	Indicator/impact domain	Variable	Sensitivity to adaptation policy	Northern		Temperate				Southern		European average	
				Boreal and Arctic		Atlantic		Continental		Medi-terranean			
				Obs	Proj	Obs	Proj	Obs	Proj	Obs	Proj	Obs	Proj
3	**Changes in the climate system**												
3.2	**Atmosphere**												
3.2.2	Global and European temperature	Temperature	No	↗		↗		↗		↗			
3.2.3	Heat extremes	Frequency of warm days/heat wave magniture index	No	↗		↗		↗		↗			
3.2.4	Mean precipitation	Annual precipitation	No	↗		↗↘	↗→	↗↘	↗→	→↘			
3.2.5	Heavy precipitation	Intensity	No	↗		↗→		→	↗	→↘	↗↘		
3.2.6	Wind storms	Maximum wind speed	No		↗→		↗→		↗→		→↘		
3.2.7	Hail	Potential hail index	No			↗→	→↘	↗↘	↗→	↗↘			
5.3	**Agriculture**												
5.3.2	Growing season for agricultural crops	Duration	No	↗		↗		↗		↗→			
5.3.3	Agrophenology	Day of spring events	Domain	↘		↘		↘		↘			
5.3.4	Water-limited crop yield	Average yield	Variable		↗		↗↘		→		↘		
		Adverse climatic conditions	Domain		↗		↗		↗→		↗→		
5.3.5	Crop water demand	Water deficit	Domain			↗↘		↗↘		↗↘	↗→		

Legend:

↗	Increase throughout most of a region	Dominating trend in at least two-thirds, opposing trend in less than 10 %	Beneficial change
↘	Decrease throughout most of aregion		Adverse change
⦣	Increase in substantial parts of a region	Trend in between one-thirds and two-thirds, opposing trend in less than 10 %	Change classified as neither adverse nor beneficial/small change
⦤	Decrease in substantial parts of a region		
<	Increases as well as decreases in a region	Trends in both directions in at least 10 %	
→	Only small changes		
*	The direction of change (European average) differs depending on the forest species, insect pest, disease and transport mode		

Notes: Obs = observation/past trend; Proj = projection.

An arrow centred between the 'Obs' and 'Proj' columns indicates agreement between observed trends and projections.

Information refers to different time horizons, emissions scenarios and socio-economic scenarios.

Impact domains in italics are not presented in indicator format.

The Continental region comprises also the Pannonian and Steppe regions.

The Mediterranean region comprises also the Black Sea region.

The Mountain region (comprising the Alpine and Anatolian regions) is too diverse to be shown separately in this table.

Warmer air temperatures have already affected the length of the growing season over large parts of Europe. Flowering and harvest dates for cereal crops are now happening several days earlier in the season. These changes are expected to continue in many regions (EEA, 2015).

In general, in northern Europe agricultural productivity might increase due to a longer growing season and an extension of the frost-free period. Warmer temperatures and longer growing seasons might also allow new crops to be cultivated. In southern Europe, however, extreme heat events and reductions in precipitation and water availability are expected to hamper crop productivity. Crop yields are also expected to vary increasingly from year to year due to extreme weather events and other factors such as pests and diseases (EEA, 2015).

In parts of the Mediterranean area, due to extreme heat and water stress in summer months, some summer crops might be cultivated in winter instead. Other areas, such as western France and south-eastern Europe, are expected to face yield reductions due to hot and dry summers without the possibility of shifting crop production into winter (EEA, 2015).

Changes in temperatures and growing seasons might also affect the proliferation and the spreading of some species, such as insects, invasive weeds, or diseases, all of which might in turn affect crop yields (EEA, 2015).

Regarding to the AEA report (AEA, 2007) whose analysis refers to a time-frame of 2050 to 2080 (distant future), risks and opportunities per agro climatic zones have been prioritised (see Table 7).

Table 7: Summary of risk and opportunity prioritisation by agro-climatic zone (AEA, 2007)

Description	Bor	Atl N	Atl C	Atl S	Cnt N	Cnt S	Alp	Md N	Md S
Risks									
Crop area changes due to decrease in optimal farming conditions		M	M	M	M	M	M	M	H
Crop productivity decrease		M	M	M	M	M	M	M	M
Increased risk of agricultural pests, diseases, weeds	H	M	H	H	H	H	M	H	H
Crop quality decrease			M	M	M	M		M	H
Increased risk of floods	H		H		H		H		
Increased risk of drought and water scarcity		H	H	H	H	H	H	H	H
Increased irrigation requirements				M		H		H	H
Water quality deterioration	H	H	H		H		H		
Soil erosion, salinisation, desertification	H			M		H	H	H	H
Loss of glaziers and alteration of permafrost	M						H		
Deterioration of conditions for livestock production	H	H	H	L	H	L	H	L	M
Sea level rise	H	H	H	H	H			H	H
Opportunities									
Crop distribution changes leading to increase in optimal farming conditions	H	H	H	M	H	H	H	M	
Crop productivity increase	M	H	M	M	M		H		
Water availability	H	M	H	H	H		M		
Lower energy costs for glasshouses	M			M	M	M		M	
Improvement in livestock productivity	H	H	H		H		H		

H=High M=Medium L=Low

Whilst influxes of new pests and diseases present a high risk in the Boreal, Atlantic central, and Continental north zones, there is likely to be considerable opportunity in these zones for increased agricultural production. The yields of current crops are set to increase, together with the area of land over which crops might be grown. There is also potential for the introduction of new crop types, and may be an opportunity for increased livestock production in some zones. However, there is also a possibility that optimal growing conditions may shift from areas that have a large proportion of fertile soils towards those where soils are less fertile and, therefore, less able to support higher yields (AEA, 2007).

In the Atlantic south, Continental south and Mediterranean zones, the greatest risks are reduced crop yields and conflicts over reduced water supply. Strategies need to be developed to adopt cultivars or crops better suited to water and heat stress. Problems from new pests and diseases are also considered a high risk in these zones. There are few opportunities, although in parts of the Continental south zone (Hungary, Romania), there may be some scope for the introduction of new crops (AEA, 2007).

1.4.2 Farming systems in Europe by climate region

To simplify the overview of the main agricultural issues in EU-28, each Member State has been whole affected to a single one-climate region. The detailed list of countries per climate zone is available under the Table 8.

Table 8: Main agricultural figures by climate region for the UE-28 (Eurostat 2013)

	Total UE-28	Atlantic	Continental	Northern	Southern
Number of holdings (1 000) %	**10 841** **100%**	943 9%	6 280 58%	394 4%	3 224 30%
Utilized agricultural area (1 000 ha) %	**174 351** **100%**	55 701 32%	61 593 35%	10 983 6%	46 075 26%
% Arable land / UAA % Permanent grassland and Meadow / UAA % Permanent crops / UAA	**60%** **34%** **6%**	54% 44% 2%	70% 28% 2%	81% 18% 0%	48% 35% 17%
Labour force (1 000 AWU) %	**9 345** **100%**	1 327 14%	5 015 54%	307 3%	2 696 29%
Average area of holdings (ha)	**16,1**	59,1	9,8	27,9	14,3
Livestock Units (1 000 LSU) %	**130 320** **100%**	55 568 43%	40 643 31%	4 492 3%	26 196 23%
Standard Output (million EUR) %	**331 568** **100%**	122 663 37%	100 883 30%	12 067 4%	95 955 29%

Atlantic: Belgium, Denmark, France, Ireland, Luxembourg, Netherlands and United Kingdom.
Continental: Austria, Bulgaria, Czech Republic, Germany, Hungary, Poland, Romania and Slovakia.
Northern: Estonia, Finland, Latvia, Lithuania and Sweden
Southern: Cyprus, Croatia, Greece, Italy, Malta, Portugal, Slovenia and Spain.

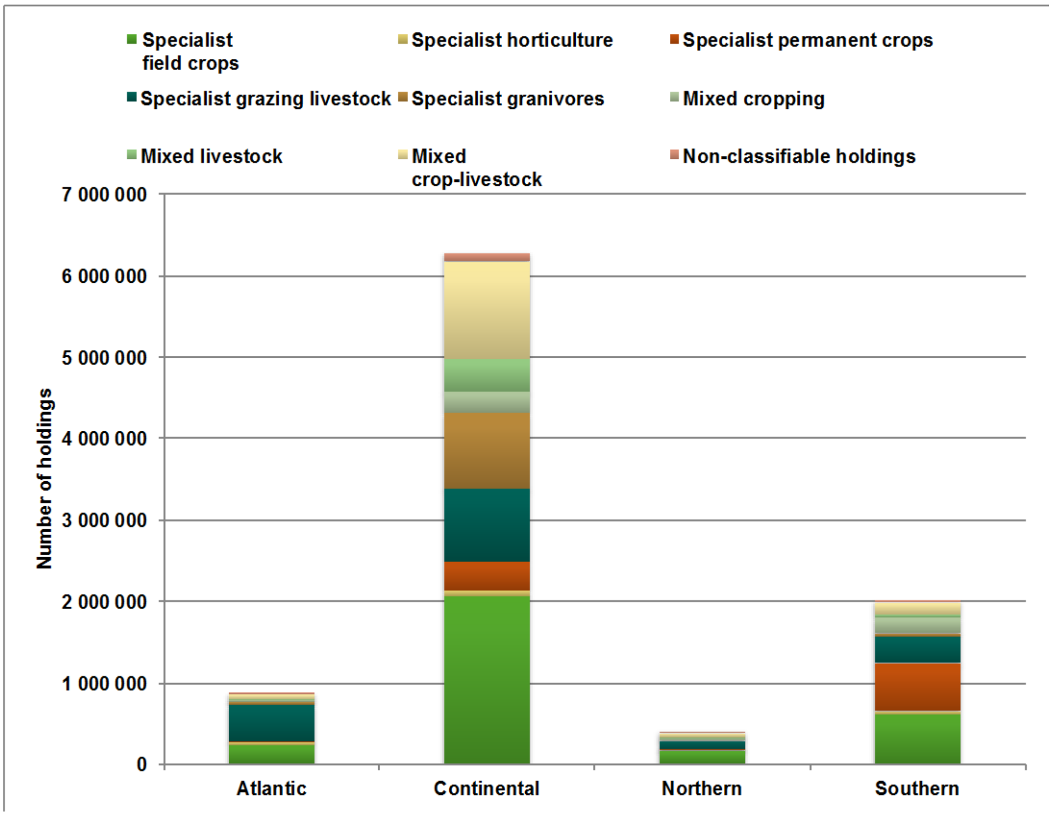


Figure 26: Agricultural holdings in 2013 (Eurostat), by farm type and by climate region

Due to the high number of holdings in Romania, the Continental zone represents **58 %** of the total holdings in EU-28, followed by the Southern zone with **30 %**.

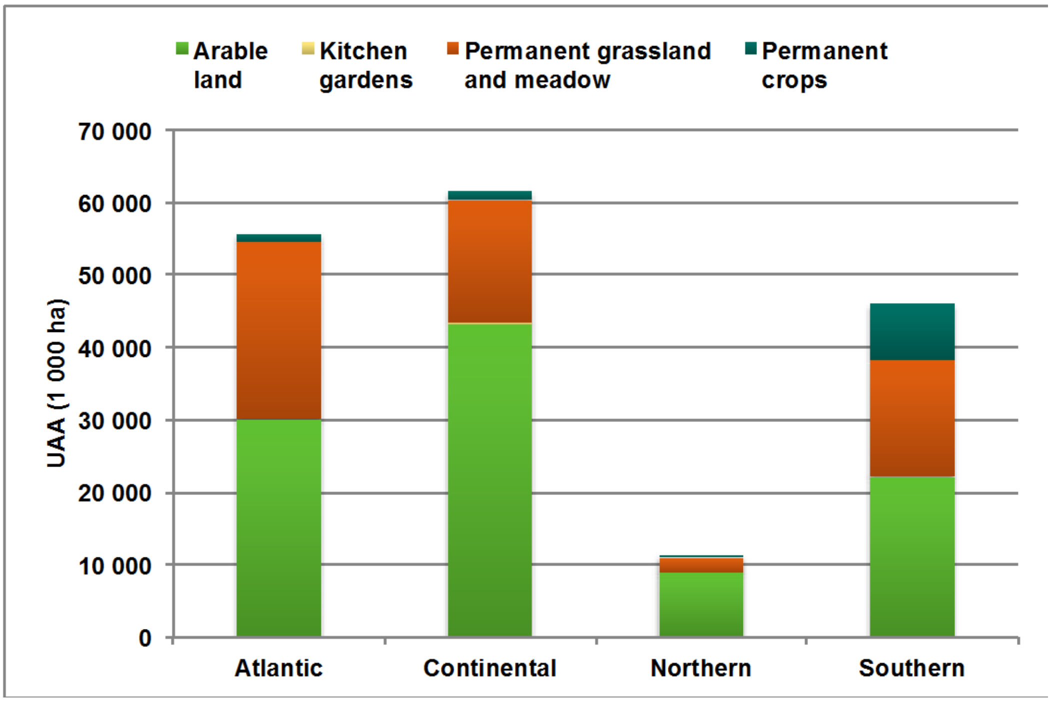


Figure 27: Utilised agricultural area (UAA) in 2013 (Eurostat), by land use and by climate region

Considering the total UAA, Continental and the Atlantic zones are dominants with respecting **35 %** and **32 %,** then the Southern zone with **26 %** and finally the Northern zone with **6 %.**

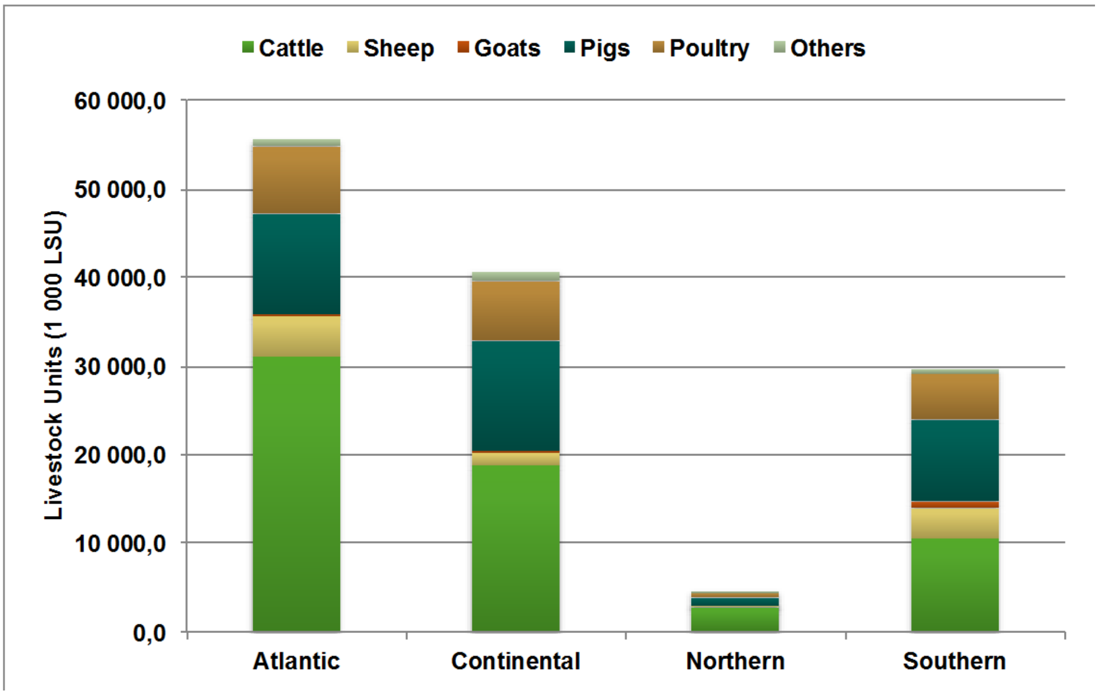


Figure 28: Livestock units in 2013 (Eurostat) by climate region

Regarding the number of LSU, the Atlantic zone is dominant with **43 %**, Continental and Southern zones are intermediate with respecting **31 %** and **23 %** finally the Northern zone with **3 %.**

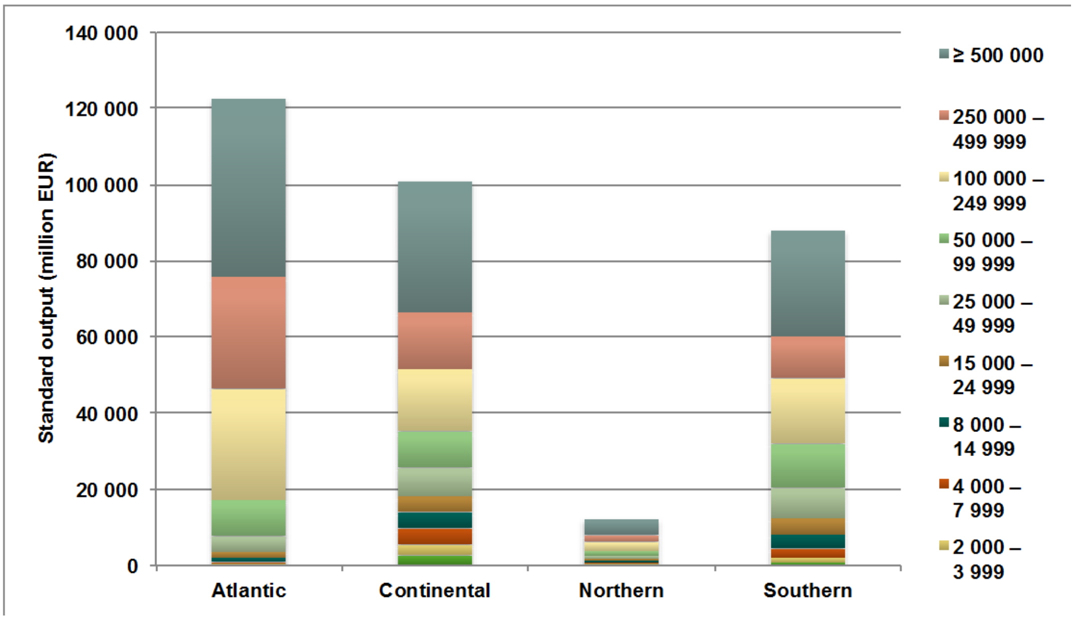


Figure 29: Standard output of agricultural holdings in 2013 (Eurostat), by economic size class and by climate region

At last, considering the standard output (million EUR), the Atlantic zone is dominant with **37 %**, Continental and Southern zones are intermediate with respecting **30 %** and **29 %** finally the Northern zone with **4 %**.

1.5 BIBLIOGRAPHY

AEA, 2007: Adaptation to climate change in the agricultural sector. AEA Energy & Environment and Universidad de Politécnica de Madrid. Report to European Commission Directorate - General for Agriculture and Rural Development, AGRI-2006-G4-05.

EEA, 2005: Vulnerability and adaptation to climate change in Europe. EEA Technical report No 7/2005, European Environment Agency.

EEA, 2012: Climate change, impacts and vulnerability in Europe 2012 — An indicator-based report, EEA Report No 12/2012, European Environment Agency.

EEA, 2013: Adaptation in Europe. Addressing risks and opportunities from climate change in the context of socio-economic developments. EEA reports No 3/2013, European Environment Agency.

EEA, 2014: Irrigation water requirement. Indicator Assessment, Data and maps, European Environment Agency.

EEA, 2015: Agriculture and climate change. Article, signals – Toward clean and smart mobility, European Environment Agency.

EEA, 2016: Global and European temperature. Indicator assessment, Data and maps, European Environment Agency.

EEA, 2016: Climate change, impacts and vulnerability in Europe 2016. An indicator-based report, European Environment Agency.

IPCC, 2014: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A:
Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1132 pp.

IPCC, 2014: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B:
Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Barros, V.R., C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 688.

JRC, 2012: Assessing Agriculture Vulnerabilities for the design of Effective Measures for Adaptation to Climate Change (AVEMAC Project). European Commission, Joint research Centre, Institute for Environment and Sustainability.

2 Atlantic Climate Zone

2.1 OVERVIEW

France is mainly dominated by the Atlantic climate zone influence even if the south of the country is under the Mediterranean climate. With about 50 % of the number of holdings of the Atlantic climate zone and 50 % of the utilized agricultural area, France situation is fairly representative of the Atlantic climate risk zone. It is the same observation for livestock, the Atlantic climate zone representing 43 % of the total EU LSU, and France representing 39 % of the Atlantic total LSU.

The crop productions in France are quite diversified. With 67 % of the French UAA, arable lands are the main type of crops cultivated, followed by permanent grasslands (30 % / UAA) and finally permanent crops (3 % / UAA). Similarly, the type of animal production in France is quite diversified, even if cattle represent half of the total LSU

Table 9: Main agricultural figures (Eurostat 2013) for UE-28, the Atlantic climate region and France (within the Atlantic region)

	Total UE-28	Atlantic	France
Number of holdings (1 000)	**10 841**	943	472,2
%	**100 %**	9 %	50 %
Utilized agricultural area (1 000 ha)	**174 351**	55 701	27 739
%	**100 %**	32 %	50 %
% Arable land / UAA	**60 %**	54 %	67 %
% Permanent grassland and Meadow / UAA	**34 %**	44 %	30 %
% Permanent crops / UAA	**6 %**	2 %	3 %
Labour force (1 000 AWU)	**9 345**	1 327	725
%	**100 %**	14 %	55 %
Average area of holdings (ha)	**16,1**	59,1	58,7
Livestock Units (1 000 LSU)	**130 320**	55 568	21 871
%	**100 %**	43 %	39 %
Standard Output (million EUR)	**331 568**	122 663	56 914
%	**100 %**	37 %	46 %

Atlantic: Belgium, Denmark, France, Ireland, Luxembourg, Netherlands and United Kingdom.

2.2 FRENCH FOCUS

2.2.1 Adaptation strategy

In France, a national adaptation strategy (NAS) was adopted in 2006[1] (MEDDE, 2011). Created in 2001, ONERC[2] is the national observatory for climate change in France that reports every year to the Prime minister and to the Parliament and provides a range of tools for adaptation planning, which can help local communities for a first approach of impacts assessment and adaptation

[1] http://climate-adapt.eea.europa.eu/countries-regions/countries/france

[2] http://www.developpement-durable.gouv.fr/The-Observatory-ONERC.html

planning. This includes indicators of observed climate change, local future climate change scenarios as well as a large documentation on climate.

Regional impact, vulnerability and adaptation studies were carried out to implement subnational adaptation planning policies (Regional Climate, Air and Energy Schemes process). The French Environment and Energy Management Agency (ADEME) supports local initiatives through training and on-line tools, in particular at regional level. A wiki-based local adaptation initiative mapping, not extensive, gathers some experiences.

France is one of the first EU Member States to produce a national adaptation plan (NAP) adopted in 2011, with a five-year implementation period. The NAP has prioritised 240 concrete measures covering the 20 thematic areas of the plan, one of which concerns agriculture. Among the 5 actions dedicated to the agricultural sector, the key measure consists in the "promotion of efficient water agriculture". A review of actions on NAP implementation took place in June 2013 and a final evaluation of the NAP started in July 2015. The update of the NAP should be done in 2017, including proposals from the stakeholders of each economic sector.

At a regional level, a Regional Scheme on Climate, Air and Energy (SRCAE) has been approved that included mitigation, air and adaptation actions and measures. The part of adaptation measures depends on the region. Then at a more local level, the SRCAE are translated into local (Cities or Inter-municipality associations) plans (PCET: Climate Plan on Energy and Territory) or Urban plans (PLU Local Urbanization Plans). The number of foreseen plans is over 400. These plans should have coherency with SRCAE, mitigation and adaptation national plans and strategies.

2.2.2 Climate Tool and Service

Since July 2012, climate projections for France are available through DRIAS[3] climate service (Providing access to Data on French Regionalized climate scenarios and Impacts on the environment and Adaptation of Societies) developed by Météo-France (national meteorological service). DRIAS is to provide easy access to French regional climate data and products in order to facilitate mitigation and adaptation studies (Météo-France, 2011). The DRIAS project focuses on existing French regional climate projections obtained from national modelling groups such as: IPSL, CERFACS, and CNRM.

2.2.3 Climate scenario for France in the 21st century

In 2010, the Ministry of Sustainable Development called upon the expertise of French climate scientists to produce a reasoned assessment of climatic conditions in France in the 21st century (MEDDE, 2014). This mission entrusted to Jean Jouzel (Vice-President of the IPCC), concluded that under scenario B2, described as optimistic, the average temperature in France will increase by approximately 2 °C to 2.5 °C between the end of the 20th century and the end of the 21st century and by about 2.5 °C to 3.5 °C under scenario A2, a more pessimistic one. Global warming is similar for both scenarios by the years 2030 and 2050, approximately ranging between 0.5 °C and 1.5 °C. The report also highlights:

- A significant downward trend in the number of heating degree-days corresponding to lower heating requirements in the future;
- An upward trend in the duration of summer droughts in all regions;
- An upward trend in the number of cooling degree-days corresponding to increased energy use for cooling in summer;
- More heatwaves and shorter cold spells having respectively negative and positive impacts on public health;
- Less snow days in general, although snow event will not disappear.

[3] http://www.drias-climat.fr/

2.2.4 Projects dealing with adaptation in agriculture

Since a few years, some studies are available in France that helps to quantify the agricultural impacts of climate change. A research platform, managed by INRA and named ACCAF metaprogram, is specifically devoted to climate change impacts and adaptation: it gathers both crops and animals studies.
The observation of yield stagnation in France for cereals certainly explains the origin of such studies. Among these reports, the research project Climator published in 2010 is probably one of the most important: it presents the climate impacts for the main crops (arable and perennial) cultivated in France (maize, wheat, rapeseed, sunflower, vineyards, grasslands) for the near future (2020-2049) and distant future (2070-2099). Results are then regionalized for 6 French sub-regions (see Figure 30), using 3 different SRES scenarios (A1 B, A2 et B1) and 5 climate models, including ARPEGE (French Model).

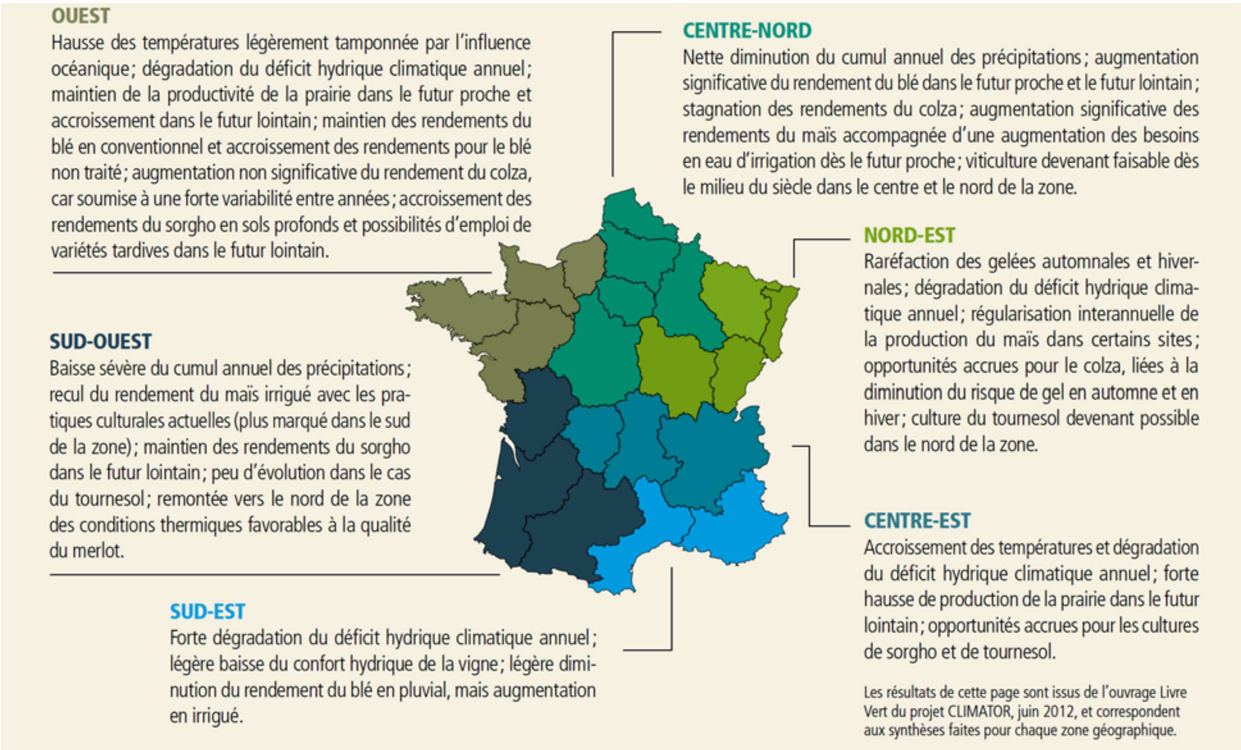


Figure 30: Regionalized impact of climate change for the main crops, Climator project

Consequently to recurrent droughts in South of France (peri-Mediterranean arch) during the 2000-2010 years involving high consequences on fodder productions, studies that specifically focus on adaptations options for herbivore farms are since then available (Climfourel, 2011), (IDELE, 2015). In addition to these farm approaches, a specific research project called Climagie (Climagie, 2015) is devoted to the adaptations of grasslands to climate change.
In 2013, the French Ministry of Agriculture has conducted a prospective study called AFClim that presents adaptation options for 9 French case studies, whether for crops farms, dairy cow milk, beef, sheep meat, vineyards and fruits. Based on a consultation of 20 different experts, climate impacts and adaptations options have been discussed and agreed collectively in terms of agronomic, economic and organizational point of view.
For vineyards and wine production, the research project LACCAVE is focused on climate change impacts and adaptation strategies, whereas few studies have been published about climate change adaptations for fruit production.
Finally, more and more local projects dealing with adaptation options in agriculture appears (AP3C, Oracle, AgriAccept, RICCMAC, ClimAdapt, Optialibio, VIADUCC, etc.), which

demonstrates reality of adapting to climate change. Among these projects, some of them consist in observatories including climatic and agro-climatic indicators in order to illustrate the observed changes and need to adapt for farmers

Table 10: List of projects dealing with adaptation for the agricultural sector in France

Project	Farming system	Scope	Contact
CLIMATOR	Arable crops Grasslands Vineyards Fruits	6 sub-regions for France	http://w3.avignon.inra.fr/projet_climator/
AFClim	All productions	National	http://agriculture.gouv.fr/afclim-agriculture-foret-climat-vers-des-strategies-dadaptation-0
ACCAF	All productions	National	http://www.accaf.inra.fr/
LACCAVE	Vineyards and wine	National	http://www.accaf.inra.fr/Actions-et-Projets/Adaptation-des-productions-vegetales/LACCAVE
ACTA/MIRES project	Herbivorous	National	
Climfourel	Fodder systems	Peri-Mediterranean arch	http://climfourel.agropolis.fr/
Climagie	Grasslands	National	http://www6.inra.fr/climagie

2.2.5 Agro-climatic grids

2.2.5.1 ARABLE CROPS

It has been proved that climatic impacts are responsible of yield stagnation in France for cereals, especially through more frequent drought and high temperatures occurring at the end of the plant cycle. From the literature and interviews from experts, the current climate risk and opportunities for the main French arable crops is presented below. From a general point of view, climate risks are limiting crop yields strongly in the south of France, whereas better yields or new crop opportunities seems possible in the north of France.

Table 11: Agro-climate grid for arable crops in France / current and recent past climate

Arable crops	Climate risks	Climate opportunities
Soft wheat	Decrease of the water comfort in spring and summer (mainly in soil with low available water content). Increase of shrivelling risk in spring. Yield reduction (from 10 % to 15 %) in the South West of France.	An increase in the number of days available for sowing. Valorisation of the increase in radiation and CO_2 concentration (C3 crop). Reduction of ear frost risk. Trend in increasing the number of grain produced. Trend in reduction of fungal diseases (reduction of infestation potential due to a reduction of air humidity).
Durum wheat	Decrease of the water comfort in spring and summer (but in comparison with soft wheat, durum wheat is more resistant to hydric stress). Increase of shrivelling risk in spring.	Same opportunities as soft wheat.
Maize	Shortening the plant cycle by more than 20 days that: - Increase the summer climate risks (water deficits and heat waves) - Shorten the grain filling period. No valorisation of the increase of CO_2 concentration (C4 crops). Large leafs, very sensitive to water stress and heat waves.	Reduction of low temperature risk for the Center and North part of France; and possibility for an earlier sowing.
Sorghum	Same observations as maize with nevertheless a better ability to face water deficit and heat waves (lower leaf index and deeper root system).	
Rapeseed	High soil drought sensibility at the first stages (crop implantation).	Reduction of the risks linked to cold temperature in winter (frost of leaf <-4 °C and Lethal temperature <-15 °C) Valorisation of the increase in radiation and CO_2 concentration (C3 crop).
Sunflower	Shortening the cycle that: - Increase the summer climate risks (water deficits and heat waves) - Shortening of the grain filling period. Flowering and filling of the grains could be affected by increase of temperature and heat waves (threshold 32 °C.) and water stress in summer Increase of inter-annual yield variability due to drought during the vegetative phase.	Reduction of the risks linked to cold temperature in spring (need a minimum of 4 °C. for germination). Valorisation of the increase in radiation and CO_2 concentration (C3 crop).

Near future (about 2030)

Observed climate trends will be intensify in the near future, accentuating the yield reduction due to high temperature and hydric stress at the end of the plant cycle. Four main crop qualities have do be taken into account to evaluate climate risks and/or opportunities: type of photosynthesis (C3 or C4 – ability to optimise increase of CO_2 concentration), crop cycle (winter or summer – ability to reduce impacts linked to summer climatic condition by growth cycle anticipation), ability to face water stresses (high or low), sensitivity to cold temperature. According to theses criteria:

- **Soft wheat** (C3, winter cycle, low ability to face water stress, low sensitivity to cold temperature):
  - Thermal increase that shorter the plant cycle (from 10 to 20 days) and reduced the summer climate risks (water deficit and heat weave).
  - Yield is expected to increase slightly from 3 % to 5 % in the Center and North part of France.
  - Yield is expected to reduce (from 10 % to 15 %) in the South West of France.
- **Durum wheat** (C3, winter cycle, high ability to face water stress, high sensitivity to cold temperature):
  - Thermal increase that shorter the plant cycle (from 10 to 20 days) and reduced the summer climate risks (water deficit and heat weave).
  - Yield reduction (by 5 %) in the South West of France (without additional irrigation).
  - Mainly present in the south of France, durum wheat should be done in the most northern areas (vigilance point: Lethal temperature - 16 °C).
- **Grain maize** (C4, summer cycle, low ability to face water stress, sensitive to cold temperature):
  - Yield decrease can be more than 25 % in the South of France (even with an with an additional water supply).
  - Small yield increase (with an additional water supply) for the Center and North part of France.
- **Sorghum** (C4, summer cycle, high ability to face water stress, sensitive to cold temperature) – same impacts as maize but with a reduction of amplitude.
- **Rapeseed** (C3, winter cycle, very sensitive to water deficit at first cycle stages, medium sensitivity to cold temperature):
  - Yield decrease (from 15 % to 25 %) in the South of France.
  - In the northeast and centre-east of France, opportunities of cropping thought the decrease of lethal frost in winter.
- **Sunflower** (C3, summer cycle, low sensitive to water deficit, high sensitivity to cold temperature):
  - Yield reduction (from 5 % to 10 %) in the South West of France (without additional irrigation).
  - In the northeast and centre-east of France, opportunities of cropping thought the decrease of cold temperature in spring.

2.2.5.2 PERMANENT CROPS

Permanent crops, such as vineyards or orchards, are well illustrating climate change through the advancement of the phonological stages (flowering date and harvest date): changes for permanent crops are often more perceptible by farmers than for annual crops. Thus, whatever the grape variety or French region, the grape harvest takes place at least two weeks earlier than in 1988. While the overall decline in harvest dates is significant and fairly irregular, year-on-year variations remain important. Preoccupations heavily focus on the future quality of wine and in the potential implementation of irrigation in terroirs of the south of France.

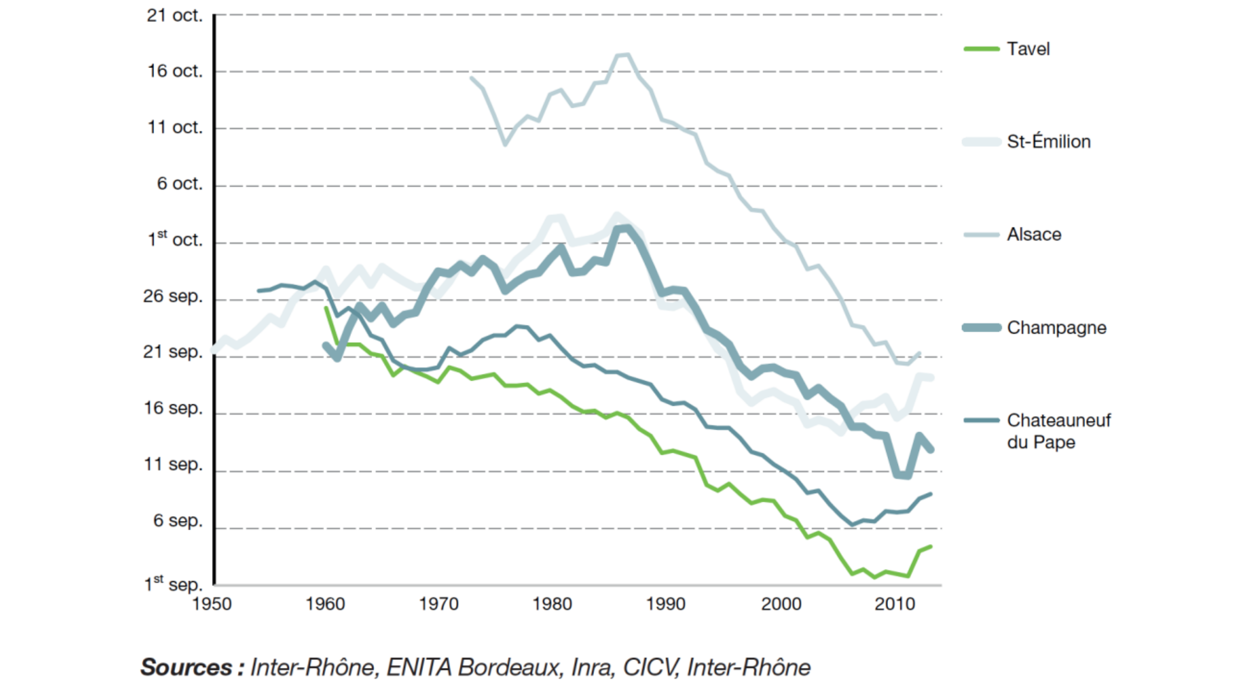


Figure 31: Evolution of grape harvest date in France

Fruit production is already vulnerable to climate change, in particular due to the strong inter-annual variability, and extreme climate events (frost on flowers, mild winters, delayed of the end of dormancy, early or late bloom, droughts, high summer temperatures, etc.). Climate risks are evenly distributed over the whole year (each season is concerned), whether through high temperatures in spring or summer (impact on fruit yield and calibre) or low temperatures in winter (dormancy). Finally, the increased water deficit is supposed to be solved with the development of better efficiency irrigation systems (best management practices) and the creation of water reserve.

Table 12: Agro-climate grid for permanent crops in France

Permanent crops	Climate risks	Climate opportunities
Vineyards	Advancement of the phenological stages (20 to 40 days) with negative consequences on grape quality due to high temperature during the maturation period. **Higher temperature in summer:** Reduction of wine quality through higher sugar content (higher alcohol degree) and low acid content. Increase in pests. **Earlier harvest date** Water deficit: (depends on irrigation systems). Decrease in annual yield and sometime better quality.	Progression of vineyards cultivation in the north. For vineyards already implemented in northern area, such as Champagne, optimal climate conditions are expected.
Apples	**Higher temperatures**: Earlier flowering date increasing risk of froze during fructification phase. Increase in pests (more generations of codling moth. Some apple varieties not adapted to warmer climate (need to change the varieties). **Low temperatures:** Cold requirements more difficult to achieve in some places. **Water deficit:** apple production (tons and calibres of fruits = smaller fruits), and maybe quality of the fruits (components). Depend on type of irrigation systems. **Extreme weather events** (hail or wind storm, mini tornado): damage on trees and sometimes the entire plot.	New varieties or new species better adapted to a (new) warmer climate.

Near future (about 2030)

For the near future, climate change impacts for orchards and vineyards should intensity and farmers would adapt mainly trough the farming practices, whereas for distant future (end of the century), adaptations options should be mainly based on new varieties and/or locations with better climate conditions.

2.2.5.3 LIVESTOCK

Direct impacts

Direct impacts of climate change are mainly related to the deterioration of animal performances (milk or meat production) due to high temperatures, which are highly impactful in case of heat waves. This problem of high temperatures concerns as much animals in buildings as outside (grazing period).

Table 13: Agro-climate grid for animals (direct impacts) in France

Animals	Climate risks	Climate opportunities
All type of animals	**High temperatures** Housed animals: needs of cooling and/or ventilation systems to preserve animal performances. Animal outside: needs of shadow through shelters/hedges that protect animals from the sun during grazing period.	

Indirect impacts

Indirect impacts through yields reduction from fodder surfaces are the most significant climate risks for livestock farms. Climate issues for these farms will be based of their type of fodder surfaces, dominance of maize (or sorghum) silage or grasslands.

Table 14: Agro-climate grid for animals (indirect impacts) in France

Fodder crops	Climate risks	Climate opportunities
Permanent grasslands and temporary grasslands	New seasonal distribution of grass growth: earlier production in spring, decreased of the summer yield production, and increased production in autumn. More production for the first cut, less for the 2nd cut. Degradation of hydric state of the grassland.	Extension of the growth period. Potential for winter grazing.
Maize silage	Advancement of the harvest date. Hydric stress.	

Near future (about 2030)

Changes linked to the climate change for the near future would therefore be small magnitude and rather positive, and the adaptations to be imagined would be rather marginal and would not encounter major constraints. However, livestock systems remain more vulnerable to climate change in the south of France, with inter-annual variability for fodder production that makes the farms vulnerable.

The contrast is strong with the distant future (end of 21st century), where it will probably be necessary to rethink totally the livestock system.

2.2.6 French bibliography

CLIMATOR, 2010: Changement climatique, agriculture et forêt en France: simulations d'impacts sur les principales espèces. Le Livre Vert du projet CLIMATOR (2007-2010), Nadine Brisson, Frédéric Levrault, éditeurs. 2010. ADEME. 336 p.

Climfourel, 2011: adaptation des systèmes fourragers et d'élevage péri-méditerranéens aux changements et aléas climatiques, un projet tri-régional Rhône-Alpes, Languedoc-Roussillon, Midi-Pyrénées. INRA.

IDELE, 2015: Herbivore livestock farming systems and climatic changes in France: conclusions from a series of studies from 2006 to 2009 (the ACTA/MIRES project).

Climagie, 2015: Adaptation des prairies semées au changement climatique. Actes du colloque présentant les méthodes et résultats du projet Climagie métaprogramme ACCAF), Poitiers, 16-17 novembre 2015.

MAAF, 2013: Agriculture, Forest, Climate: towards adaptation startegies. Centre d'Etudes et de Prospective, Ministère de l'Agriculture, de l'Agroalimentaire et de la Forêt, 2013

MEDDE, 2011: French national Climate Change Impact Adaptation Plan 2011 – 2015. Ministère de l'Ecologie, du Développement Durable et de l'Energie.

MEDDE, 2014: Le climat de la France au XXI^{e} siècle, Volume 4, Scénarios régionalisés édition 2014 pour la métropole et les regions d'outre mer. Rapports, Direction générale de l'Energie et du Climat, Ministère de l'Ecologie, du Développement Durable et de l'Energie. G. Ouzeau, M. Déqué, M. Jouini, S. Planton, R. Vautard, Sous la direction de Jean Jouzel, août 2014.

Météo-France, 2011: DRIAS: a step toward Climate Services in France. Advances in Science & Research, 10th EMS Annual Meeting and 8th European Conference on Applied Climatology (ECAC), 2010.

List of French experts identified

- Meteorologist: M. Pigeon (Météo-France)
- Agronomists: M. Levrault (CRANA), M. Gate (Arvalis), M. Gouache (Arvalis), M Leconte (Terres Inovia), M. Justes (INRA).
- Livestock: M. Moreau (IDELE), M. Duru (INRA), M. Martin (INRA)
- Vineyards: M. Touzard (INRA),
- Fruits: M. Jay (CTIFL), M. Loquet (CTIFL), M. Mathieu (CTIFL), M. Legave (INRA)

3 Continental Climate Zone

3.1 OVERVIEW

About 35 % of the overall utilised agricultural land in the EU is located in the Continental climate region, which extends over eight countries (Table 15). Of this agricultural land, about 27 % is located in Germany. Therefore, Germany can be viewed as representative of the Continental climate region in terms of agriculture.

Table 15: Main agricultural figures (Eurostat 2013) for EU-28, the Continental climate region and the share of Germany within the Continental climate region

	Total UE-28	Continental	Germany
Number of holdings (1 000)	**10 841**	**6 280**	**285**
%	**100 %**	**58 %**	**5 %**
Utilized agricultural area (1 000 ha)	**174 351**	**61 593**	**16 700**
%	**100 %**	**35%**	**27 %**
% Arable land / UAA	**60 %**	**70 %**	**71 %**
% Permanent grassland and Meadow / UAA	**34 %**	**28 %**	**28 %**
% Permanent crops / UAA	**6 %**	**2 %**	**1 %**
Labour force (1 000 AWU)	**9 345**	**5 015**	**523**
%	**100 %**	**54 %**	**10 %**
Average area of holdings (ha)	**16,1**	**9,8**	**58,6**
Livestock Units (1 000 LSU)	**130 320**	**40 643**	**18 407**
%	**100 %**	**31 %**	**45 %**
Standard Output (million EUR)	**331 568**	**100 883**	**46 252**
%	**100 %**	**30 %**	**46 %**

Continental: Austria, Bulgaria, Czech Republic, Germany, Hungary, Poland, Romania and Slovakia.

3.2 GERMAN FOCUS

3.2.1 Climate trends & National Adaptation Strategy

The German Strategy for adaptation to climate change (Deutsche Anpassungsstrategie an den Klimawandel) was created in 2008 by the German Federal Government. The goal of the German Federal Government is to limit the increase in temperature by 2°C compared to pre-industrial times. Impacts of climate change should be mitigated, therefore the long-term goal of the Adaptation Strategy is to reduce the vulnerability to climate change and to increase the adaptability. The German Strategy for adaptation can be found on the European Climate Adaptation Platform under following link: http://climate-adapt.eea.europa.eu/countries-regions/countries/germany

The national adaptation strategy details overall climate trends for Germany and then focuses on all the relevant sectors in Germany, including the agricultural one.

The main climate trends for Germany are an increase in precipitation in winter and spring, an increase in the annual mean temperature of 0.5 -1.5 °C in the near (2021 -2050) and of 1.5 – 3.5 °C in the far future (2071 – 2100) compared to the climate normal period of 1961 – 1990, as well as an increase in extreme weather events.

On the regional level, an adaptation strategy for the federal state of Baden-Württemberg exists since 2015. This climate change adaptation strategy describes the climate trends for Baden-Württemberg and focuses on the chances and challenges, as well as adaptation strategies for all sectors. It is produced by the Ministry for Environment, Climate and Energy.

The main climate trends for Baden-Württemberg are similar to those predicted for Germany. There will be an increase in the temperature, less in the mountainous region than in the lowlands. For the near future (2021 - 2050) an increase of the annual average temperature from 8.4 °C to 9.5 °C is predicted. The projected increase in average annual temperature for the far future (2071 – 2100) will be to a temperature of 11.5 °C. The number of tropical days (daily maximum ≥ 30 °C) will increase dramatically. Nowadays there is an average of 4 tropical days per year. This number is projected to increase by 2.7 days in the near future and by 20.8 days in the far future.
The projections for precipitation vary slightly more than the temperature projections. While a clear trend is not visible, it seems that the total amount of precipitation per year will not increase. A shift of precipitation from the summer to the winter months as well as an increase in the number of days with heavy rainfall is projected (Ministerium für Umwelt, Klima und Energiewirtschaft, 2015). The latter will occur predominantly in the winter months (September – April) (Flaig, 2013; Gömann et al., 2015). The amount of daily maximum precipitation over a year will increase by 13 % in the far future. This increase in heavy rainfall will increase the risk of soil erosion and of runoff from pesticides into surface water (Flaig, 2013).
There will not only be an increase in the number of days with heavy rainfall in the future but a decline in precipitation between March and May is projected as well. These months are extremely important for the development of winter cereals. For Baden-Württemberg the precipitation decline in the above mentioned months has been seen in the past, but there is a variability in the trend when looking at the whole of Germany (Gömann et al., 2015). As this trend is very variable within Germany and within the 3 months itself, not too much weight should be placed on it.
Another important factor for the agricultural sector is the water balance. A slight change in the water balance of Baden-Württemberg is projected for the near and far future. There will be a reduction of the water balance for July and August and an increase in all the other months. Although the water balance will remain positive, the water balance in July and August will be marginally above zero. (Ministerium für Umwelt, Klima und Energiewirtschaft, 2015)

One should keep in mind that all of the projections have been made with the A1B scenario from the IPCC (2001). The scenario family A1 describes a rapid growth in economy, the peaking of global population in the middle of the century, and rapid technological innovation. In scenario A1B, the growing demand for energy is met by a scenario mix of fossil and non-fossil energy sources. It is therefore a rather moderate scenario. Most climate projections have been presented with the 50 percentile, which means that it only is the median and not necessarily the most probable development of the climate. The development of greenhouse gas emissions suggests to take the 15 percentiles into account for drought, and the 85 percentiles for heat stress, so the projections would actually be more extreme in these cases. One however should keep in mind that all projections are estimates.

As in the German adaptation strategy, all sectors are addressed in the regional adaptation strategy for Baden-Württemberg, including the agricultural one. Main adaptation measures for agriculture in Baden-Württemberg, detailed in the regional adaptation strategy, have the goal of reducing the agricultural damage and at the same time of using the chances of the changing climate. Adaptation measures focus on all aspects of climate change equally: increase in temperature, increase of extreme weather events, and change of the precipitation pattern.

3.2.2 Climate Tool or services

The main climate tool available in Germany is the German Climate Atlas "Deutscher Klimaatlas", a tool created by Germany´s national meteorological service (DWD). Past data is available as a reference map as well as data of the current year and climate projections. The data is available on national and regional level for 26 indicators. These include general indicators, such as average temperature, number of hot days, days below zero, and specific agricultural indicators, such as soil moisture, Huglin Index and the yield of grassland. For the climate projections, the tool uses the emission scenario A1B for projections from 2010 – 2100. Maps for the emission scenarios RCP4.5, RCP6, RCP8.5 are in the process of being produced by the DWD.
http://www.dwd.de/EN/climate_environment/climateatlas/climateatlas_node.html

A second, regional climate tool is available from the LUBW (Landesanstalt für Umwelt, Messungen und Naturschutz Baden-Württemberg) for a set of 28 indicators. These are all general indicators and do not include specific agricultural indicators. A series of 24 climate projections were analysed for the climate parameters of the near future and 15 climate projections were analysed for the far future. All climate projections used the A1B scenario.
http://www4.lubw.baden-wuerttemberg.de/servlet/is/233728/

3.2.3 Projects dealing with adaptation in agriculture

A European project dealing with climate change mitigation and adaptation is the SOLMACC project, lead by IFOAM EU in Belgium. It focuses on organic farms of all farming systems in Germany, Sweden and Italy. The goal is to share project outcomes with the farming community and policy makers in the EU as well as in the respective countries.
Projects on the national level of Germany have not been included in the table because the number of regional projects dealing with climate change and adaptation options is greater than the number of national projects.
A regional project dealing with viticulture in the federal state of Saxony Anhalt is the project LIFE VinEcoS. Increasing temperatures and in general climate change, will lead to more land-use conflicts. This is why this project will test adaptation methods in vineyards, with a specific focus on optimising its ecosystem services.
Two finalised regional projects on adaptation to climate change in the federal state of Baden-Württemberg are shown in Table 16. Both projects focus on areas (Black Forest, Lake Constance) in which climate change will play a big role in the far future, especially through the increase in temperatures. These two projects dealt with all farming systems, arable, livestock and permanent crops, assessed the vulnerability of the farms and gave adaptation options on a the single farm level.

Table 16: List of projects dealing with adaptation for the agricultural sector in Germany

Project	Farming system	Scope (national, regional)	Contact (name, email, web)
Landschaft im Klimawandel – Anpassungsstrategien für den Naturpark Südschwarzwald	Arable, permanent crop and livestock	Regional	Suzanne van Dijk Suzanne.vanDijk@unique-landuse.de
VinEcoS Optimizing Ecosystem Services in Viniculture facing Climate Change	Permanent crop	Regional	Jörn Freyer, freyer.j@lgsa.de
SOLMACC (Organic farmers countering climate change)	Arable, permanent crop and livestock	National (EU-Wide)	Ann-Kathrin Trappenberg ann-kathrin.trappenberg@ifoam-eu.org http://solmacc.eu/
Anpassung der Landwirtschaft an den Klimawandel	Arable, permanent crop and livestock	International (Lake Constance region – Germany, Switzerland and Austria)	Maximilian Dendl, IBK AG Landwirtschaft und Umwelt maximilian.dendl@aelf-ke.bayern.de http://landwirtschaft.bodenseekonferenz.org/41045/Anpassung-der-Landwirtschaft-an-den-Klimawandel/landw_index.aspx

3.2.4 Agro-climatic grids

In the year 2014, 15.3 % of the farms in Germany had a focus on the production of arable crops, 6.1 % on permanent crops (viticulture and fruit production) and 57.5 % on livestock. The remaining 21.2 % of the farms were mainly mixed (16.3 %) and horticultural farms (4.9 %) (BMEL, 2015). Mixed farms are farms in which no production system generates over 50 % of the farm income.

The distribution of the production systems was slightly different in the state of Baden-Württemberg for the year 2013. Here, 25 % of the farms produced arable crops, 20 % produced permanent crops, 39 % were livestock farms and the remaining 17 % were divided into 14 % mixed farms and 3 % horticultural farms (Statistisches Landesamt Baden-Württemberg, 2014).

3.2.4.1 ARABLE CROPS

Higher temperatures, heat stress and excess water are the climatic factors which pose the highest risk to arable crops in Germany as well as in Baden-Württemberg. These climate risks result in most cases in a decrease of yield and/or quality of the crop and an increase in pests (Table 17).

Climate opportunities exist in few cases as well. Through the increase in temperature, the growing region for maize can expand, root crops can have a longer vegetation period and pests of moist environments may be reduced.

Table 17: Agro-climate grid for arable crops in Germany

Arable crops	Climate risks	Climate opportunities
Winter wheat	**Higher temperatures** Reduced corn filling phase and lower yield[4], winter wheat more prone to pests, increase in pests **Excess water September – March** Winter wheat yield reduction (root formation affected) - **Excess water in July/August (heavy rainfall)** High grain moisture content, harvest not possible **Heat stress** Reduction in yield	**Higher temperatures** Reduction of pests of moist environments (e.g. *Rhynchosporium*)
Maize	**Higher temperatures** Increase in pests **Water deficit during growth period** Decrease in yield **Excess water** in summer Grain loss **Excess water** in October High grain moisture content, harvest not possible	**Higher temperatures** Increase in growing region
Winter barley	**Higher temperatures** Reduced corn filling phase and lower yield, more prone to pests, increase in pests **Excess water September – March** Reduction in yield (root formation affected) **Excess water in July/August -** High grain moisture content, harvest not possible **Heat stress -** Reduction in yield	**Water deficit** More drought resistant than wheat but economically not on the agenda)
Sugar beet	**Heat stress** Increase of amino-n contents **Water deficit** in June Plant needs more water	
Potatoes	**Higher temperature** and drier Increase in pests **Heat stress** Reduction in yield. From 40 °C heat death of the potato tuber **Excess water** Water logging can lead to an increase in rotting of the plant, heavy precipitation can lead to the washing away of the potato ridge	**Higher temperatures** Earlier “sowing” dates
Rapeseed	**Heat stress** Reduction of oil content **Excess water** May August - Breaking of the pod before harvest	

Excess water is a climatic factor that poses a risk to all arable crops. Excess water during the harvest impairs the access to the field for harvesting machinery and leads to the compaction of soil. Excess water before the harvest increases the moisture content in the crops and leads to problems with fungi when the crops are stored.

[4] The higher temperatures that may lead to a reduced corn-filling phase are only higher temperatures during the period of a couple of days

Near future (about 2030):

Analyses of weather stations already show an increase of spring drought in March and April and an increase in heat stress during the flowering phase of winter wheat. Climate projections show a further increase in heat stress but no increase in the spring drought. Other than the heat stress, no significant accumulation of any extreme weather events relevant to arable crops was observed (Gömann et al., 2015).

This means that all vulnerability facts related to heat stress will become stronger in the near future while vulnerability facts related to spring drought will stay the same. Nevertheless, there will be a water deficit in the vegetative phase of the plants and this will lead to a decrease in all crop yields/decrease in quality of the crops. As the climate projections show an increase of the average annual temperature, all vulnerability facts related to higher temperatures will become stronger and vulnerability facts related to excess water will become stronger in some parts of Germany as well.

3.2.4.2 PERMANENT CROPS

The climate risks which are the most prevalent in permanent crops are linked to an increase in extreme weather events, e.g. through hail damage and heat stress (Table 18). These weather events lead to damage of the fruits and to a decline in fruit quality. Climate opportunities, in both cases, are the cultivation of varieties adapted to warmer climates.

Table 18: Agro-climate grid for permanent crops in Germany

Permanent crops	Climate risks	Climate opportunities
Vineyards	**Higher temperatures** Reduction of wine quality through higher sugar content and low acid content (e.g. for the Riesling). Increase in pests e.g. European grape berry moth having 3 generations instead of 2. **Higher temperatures in winter** Earlier shooting of vines leads to higher danger of late frosts. **Heat stress** Premature ripening, young vines cannot cope. **Increase in extreme weather events** Higher hail damage and therefore loss of quality. **Water deficit** Decrease in wine quality (decrease in reserve material deposition in younger plants, hard and inelastic grape skin). **Excess water** Difficult access for machinery. **Excess water through heavy rainfall + higher temperatures** Increase in infections (e.g. Botrytis), bursting of fruits.	**Higher temperatures** Different grape varieties adapted to warmer climate (e.g. Syrah) can be cultivated as well.
Apples	**Higher temperatures** Increase in pests (Powdery mildew, fire blight during the flowering phase relevant). Codling moth has more generations. **Heat stress** Reduction in yield and quality (sunburn). **Water deficit** Decrease in apple quality (smaller fruits). **Excess water** Increase in infections (e.g. apple scab, fruit tree canker). Increase in **extreme weather events -** Higher hail damage in areas without hail nets.	**Higher temperatures -**Cultivation of apple varieties adapted to warmer climate (e.g. Pink Lady).

For viticulture most climate risks are related to the wine quality and do not have an effect, or only a very small one, on the vine itself. Vines can cope with higher temperatures and heat stress quite well. The Riesling, a grape variety originated in the Rhine region of Germany, however, needs cool nights and a moderate climate in order to produce a high wine quality. This variety will be the one most affected by the changing climate in Germany, especially through the higher temperatures. As the Riesling is mostly grown in Rhineland-Palatinate, this region will need to implement adaptation measures concerning the growth of different grape varieties.

Near future (about 2030):

Hail has the highest damage potential in permanent crops, followed by late frost. The extreme weather events that have the highest risks vary according to the cultivation region in Germany. In Baden-Württemberg water deficit is the second highest risk, compared to late frost in the Lower Elbe.

A query, conducted by the DWD, showed that the risk of following climatic factors will increase in apple cultivation in the future:

- Heat stress (April – September)
- Continual rainfall (March – April)
- Heavy rainfall (March – October)

- High evening temperatures (May – September)

For viticulture, the risk will increase with following climatic factors:

- Heat stress (May – September)
- Heavy rainfall (April, May, September and October)
- Drought (July and September)
- High autumn and winter temperatures

(Gömann et al., 2015)

This means that the vulnerability facts linked to the above mentioned climatic factors will become stronger in the near future. All these climatic factors have been mentioned in the agro-climate grid for apples and vines.

3.2.4.3 LIVESTOCK

Direct impacts

Livestock can be affected directly, through the changing climate or indirectly through impacts on fodder production. Both need to be considered when dealing with the changing climate and measures for adaptation.
For livestock the main risk originates from heat stress due to higher ambient temperatures. As can be seen in Table 19 heat stress results in a decrease of milk production in dairy cattle and can result in circulatory problems and higher death rates in pigs and poultry.

Table 19: Agro-climate grid for animals (direct impacts) in Germany

Animals	Climate risks	Climate opportunities
Dairy Cattle	**Heat stress** Decrease of milk production (20 %), reduction of fertility **Higher temperatures** Increase of animal diseases, reduction of fat content of the milk	
Pigs	**High temperatures and heat stress** Circulatory problems and higher death rates	**Higher temperatures** Less heating required for barns in winter
Poultry	**Higher temperatures** Circulatory problems, increase in respiratory diseases **Heat stress** Higher death rates, reduction in egg production	

Indirect impacts

For the fodder crops, a water deficit during the vegetative phase results in lower yields, and can change the plant composition in permanent grasslands. Excess water also imposes a risk in all cases (Table 20) as grazing might not be possible and machinery access is impaired as well. If harvesting time points need to be shifted, due to excess water, this may result in a reduction of feed quality.

Table 20: Agro-climate grid for animals (indirect impacts) in Germany

Fodder crops	Climate risks	Climate opportunities
Permanent grasslands	**Water deficit during the vegetation phase** Plant composition changes **Water deficit** Earlier "ripe" and therefore reduction in feed quality **Heat stress in July** Reduction in grass biomass **Excess water** Not accessible for machinery, grazing not possible	**Higher temperatures** Perennial ryegrass will have less problems with snow mould and frost in winter
Temporary grasslands	**Higher temperatures** Cutting time point will be earlier **Excess water** Grazing not possible Not accessible for machinery	Flexibility for sowing which fodder is missing and which is adapted to the current weather
Maize silage	**Higher temperatures** Increase in pests (leaf blotch) **Water deficit during growth period** Decrease in yield **Excess water** in summer Grain loss **Excess water** in October High grain moisture content, harvest not possible	
Clover, grass-clover and alfalfa	**Water deficit** Lower yield **Excess water** Not accessible for machinery	

Excess water leads to an increase in fungal infections in all cereals which has an indirect effect, particularly on pigs and poultry as they cannot cope with high concentrations of mycotoxins in fodder.

Near future (about 2030):

Direct climate risks and opportunities

There will be an increase in the number of tropical days and of the average temperature in the near future. As the increase in average temperature in the near future will only be by 1 °C, current barns will be able to regulate this difference. Heat stress on tropical days, however, will be a problem as the ambient air cannot be cooled by more than 4 °C compared to the outside temperature. Unless barns are equipped with the newest technologies for cooling, the risk of heat stress and of higher temperatures will become stronger in the near future. This vulnerability fact concerns dairy cattle, poultry and pigs.

Indirect climate risks and opportunities

Water deficit during the vegetation phase is the main problem for animal fodder. Farmers need to react to this problem by building up of stocks. Therefore, a higher storage capacity for silage and hay will be needed, as well as the rationing in smaller amounts to compensate for sudden feed loss when fodder cannot be harvested. There has already been an increase in spring drought up until now and this will remain stable till the near future. The vulnerability facts concerning water deficit will therefore stay the same.

Vulnerability facts concerning higher temperatures will increase slightly in the near future and vulnerability facts related to excess water will become stronger in some parts of Germany as well.

Other factors that have not been included in the agro-climatic table but are important are the storage capacity of manure and the increase in CO_2 concentrations. Due to more frequent situations of water deficit as well as water excess (extreme weather events), the application of organic fertiliser/manure needs to be shifted in time. Therefore, a higher storage capacity is required. Currently there is a storage capacity of 6 months.

Higher CO_2 concentrations result in an increase of grassland growth of about 12 % in the absence of extreme weather events. An increased CO_2 concentration combined with heat stress or excess water (heavy rainfall), however, results in a decrease of biomass compared to the current normal weather conditions. An increase in CO_2 concentrations has not only resulted in an increase in grassland biomass, all C3 plants seem to produce more biomass with elevated CO_2 concentrations. Extreme weather events, however, decrease the production of biomass for arable crops as well. These interactions have to be taken into account when looking at the development of grasslands and arable crops.

3.2.5 German bibliography

Relevant information was gathered from (Flaig, 2013), (Gömann et al., 2015) and (Ministerium für Umwelt, Klima und Energiewirtschaft, 2015) as well as from expert interviews.

BMEL. (2015). *Agarpolitischer Bericht der Bundesregierung 2015*. Berlin: Bundesministerium für Ernährung und Landwirtschaft.

Flaig, H. (2013). Anpassungsstrategie Baden-Wüttemberg an die Folgen des Klimawandels - Fachgutachten für das Handlungsfeld Landwirtschaft.

Gömann, H., Bender, A., Bolte, A., Dirksmeyer, W., Englert, H., Feil, J.-H., … Zimmer, Y. (2015). *Agrarrelevante Extremwetterlagen und Möglichkeiten von Risikomanagementsystemem: Studie im Auftrag des Bundesministerium für Ernährung und Landwirtschaft (BMEL)* (Abschlussbericht) (p. 312). Braunschweig: Johann von Thünen-Institut.

International Panel on Climate Change (IPCC): Climate Change 2001: T*he Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change*. HOUGHTON, J.T.; DING, Y; GRIGGS, D.J.; NOGUER, M.; VAN DER LINDEN, P.J. et al., Cambridge/New York: Cambridge University Press, 2001, 94 S. [http://ipcc.ch/ipccreports/tar/wg1/index.htm]

Ministerium für Umwelt, Klima und Energiewirtschaft. (2015). *Strategie zur Anpassung an den Klimawandel in Baden-Württemberg*.

Statistisches Landesamt Baden-Württemberg. (2014). Landwirtschaft in Baden-Württemberg.

List of German experts identified

- Agronomists: Dr. H. Flaig (LTZ Augustenberg), Prof. Dr. M. Elsässer (LAZBW Aulendorf)
- Livestock: Hansjörg Schrade (LSZ Boxberg), Dr. M. Effenberger (LfL Bayern), Prof. Dr. M. Grashorn (University of Hohenheim)
- Vineyards: Dr. M. Breuer (WBI Freiburg)
- Fruits: Dr. U. Mayr (KOB)

4 Southern Climate Zone

4.1 OVERVIEW

Climate change experts agree upon the fact that the Mediterranean region will be among the most affected world regions especially affecting critical variables for agriculture, such as reduced precipitation and increased frequency of extreme events. Projections from climate change scenarios have also shown to hold a lower degree of uncertainty for Mediterranean areas than for the rest of EU climate regions. And effect of the improvements of climate change scenarios' accuracy will be less significant for assessing Mediterranean agriculture impacts than for other climates, as Mediterranean agriculture already encompasses very limiting conditions (i.e. when reduction in summer rain or an increase in lethal temperatures is already critical, more accurate projections will not change significantly the expected effects). As a result, the Mediterranean area is in urgent need of practical adaptation solutions.

Climate change is expected to have a non-uniform effect on the Spanish farmland, due to its complex orography, climate areas (Atlantic, North Mediterranean, South Mediterranean, Mountain Mediterranean) and production models. However, it seems that positive effects (CO_2, warmer temperatures, frost-free seasons, etc.) will barely compensate the negative ones or will just reduce the urgency of addressing adaptative solutions in particular sectors and/or areas. Extreme and unpredicted weather events, to which plants are less adapted than for long-term changes, are thought to counteract the potential positive effects found.

Irrigated and rainfed agriculture (accounting for up to 75 % of the Spanish farmland), as well as some Mediterranean regions already facing water scarcity and extreme temperatures, will be among the most affected ones. Under most of the climate change scenarios, rainfed agriculture will be still feasible, although more frequent extreme and unpredictable events will expose these productive models to economic uncertainties that will threaten its profitability in the long term.

Water is identified as one of the main drivers to reduce the impact of climate change on agriculture. In that sense, the National policies for water management will have to be carefully planned along with agricultural strategies and climate-wise decisions. For example, new irrigated areas for vineyard in Central Spain have not been planned under a climate perspective, and the growing conditions in some of these areas would be in a few decades very different to the current ones, something especially critical for a permanent crop that needs several years for reaching its maximum yield, which makes adaptation more difficult for this crop types. The same situation can be critical for new irrigated areas devoted to arable crops in areas already facing adverse temperatures, that may become lethal or not adequate to sustain profitability in the near future, since arable crops yields could decrease.

In the Mediterranean countries (i.e. in Spain where agriculture water accounts in some regions for 70 % of the total water use), any decision adopted in that sense will be determinant for the future of the sector. This situation is really challenging, due to Water Framework Directive compliance, to the unbalanced economic incomes from irrigated and rainfed agriculture, to the extreme scarcity of this resource in some areas (according to the Spanish Ministry, a mean reduction of 17 % of water resources is expected for 2060 in the Iberian Peninsula due to the combined effect of temperature increase and precipitation reduction, with some Southern areas more affected), to the traditional social conflicts around agriculture and the water rights, etc.

Other non-analysed variables (or with still poor information), will be also crucial for understanding the situation of Spanish agriculture in the midterm. We wonder for example to which extent the high mean age of farmers, the low production diversification in some areas, the low degree of professional farmers or the high number of smallholdings will affect the adaptative response to climate change and to farming sustainability in general. More research is also needed in unique and high value agrosystems, such as dehesas, mountain areas or seminatural habitats managed by farmers, with a strong relationship to biodiversity conservation.

Table 21: Main agricultural figures (Eurostat 2013) for UE-28, the Southern climate region and the share of Spain within the Southern climate region

	Total EU-28	**Southern**	**Spain**
Number of holdings (1 000)	**10 841**	3 224	965
%	**100 %**	30 %	30 %
Utilized agricultural area (1 000 ha)	174 351	46 075	23 300
%	100 %	26 %	51 %
% Arable land / UAA	60 %	48 %	48 %
% Permanent grassland and Meadow / UAA	34 %	35 %	35 %
% Permanent crops / UAA	6 %	17 %	17 %
Labour force (1 000 AWU)	9 345	2 696	814
%	100 %	29 %	30 %
Average area of holdings (ha)	16,1	14,3	24,1
Livestock Units (1 000 LSU)	130 320	26 196	14 502
%	100 %	23 %	55 %
Standard Output (million EUR)	331 568	95 955	35 979
%	100 %	29 %	37 %

Southern: Cyprus, Croatia, Greece, Italy, Malta, Portugal, Slovenia and Spain.

It will also be necessary to have more specific information about agroforestry. Agroforestry is the practice of deliberately integrating woody vegetation (trees or shrubs) with crops and/or animal systems to benefit from the resulting ecological and economic interactions. In the case of countries, such as Cyprus, Greece, Malta, Italy, Portugal, Slovenia and Spain the surface devoted to agroforestry systems is very relevant, both in terms of surface and UAA share (see Figure 32), and for the EU it accounts for up to 8.8 % of the UAA.

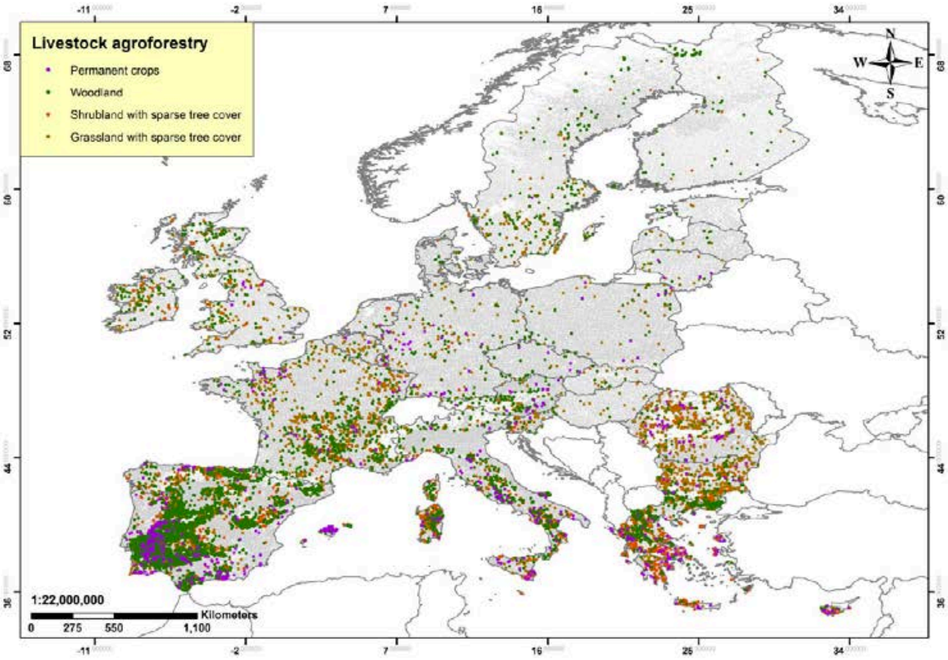


Figure 32: Distribution of agroforestry for livestock systems including permanent crops (fruits, olives and nuts), woodland, shrub land and grassland with sparse tree cover. Source: Current extent and trends of agroforestry in the EU27. AGFORDWARD.

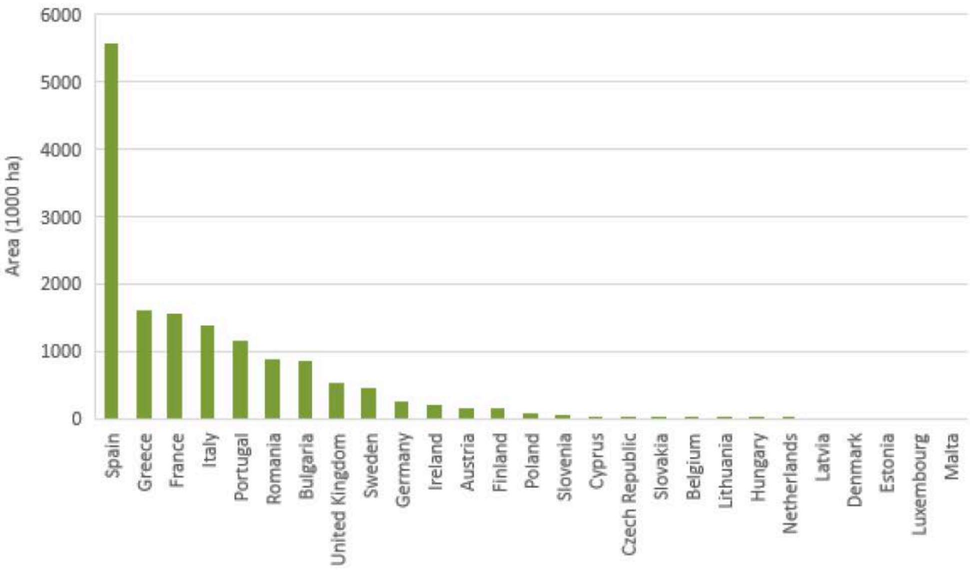


Figure 33: Estimated extend (x1000 ha) of area covered by agroforestry systems in the EU27 Source : Current extent and trends of agroforestry in the EU27. AGFORDWARD.

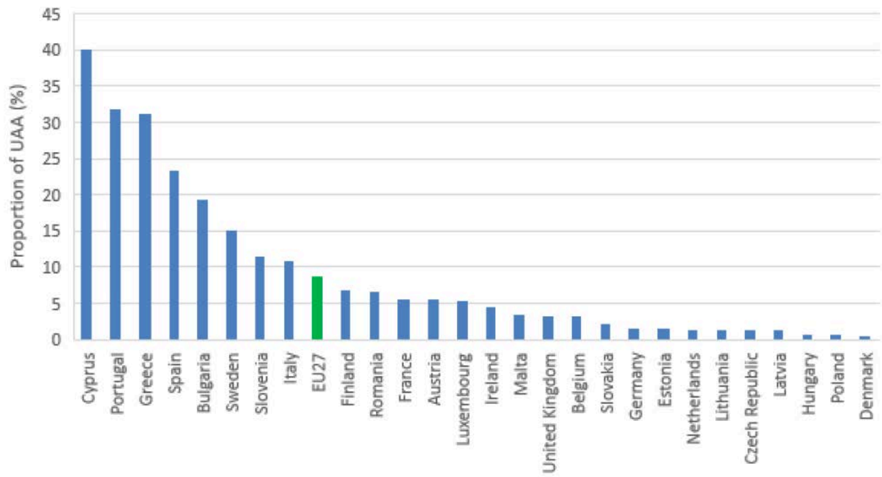


Figure 34: Estimated extend of agrofoerstry as a proportion of the Utilised Agriculture Area in the EU27. Source: Current extent and trends of agroforestry in the EU27. AGFORDWARD.

Spain (5.6 million ha), Greece (1.6 million ha), France (1.6 million ha), Italy (1.4 million ha) and Portugal (1.2 million ha) have the largest absolute extent of agroforestry. However, if we would look at the extent of agroforestry in relation to the utilised agricultural area (UAA), countries like Cyprus (40 % of UAA), Portugal (32 % of UAA) and Greece (31 % of UAA) have the largest percentage of agroforestry cover. (AGFORWARD, 2015). In Spain and Portugal agroforestry is mainly represented in “dehesas” and “montados”. These agroforestry systems in Spain and Portugal are among the most diverse high nature value systems in Europe. Iberian dehesas are open oak woodlands devoted to livestock rearing and in more fertile soils periodically cultivated with cereal and/or fodder crops. This is why agroforesty in general, and dehesas in particular, are addressed in this project, taking in account their components and interactions between cattle, pasture, crops and trees.

4.2 SPANISH FOCUS

4.2.1 Climate trends & National Adaptation Strategy

In the Mediterranean region the temperature will show a higher-than-average increase, sharper in the summer months than in the winter ones. For the RCP8.5 scenario and for the end of the XXI century, the Mediterranean region will suffer average temperature increases of 3.8 ºC and 6.0ºC in the winter and summer months, respectively, and average rainfall decreases of 12% and 24% in the winter and summer months, respectively. There will be an increase in the extremes related to rainfalls originated by storms (IPCC 2013). In Spain, according to the data collection called "PNACC Scenarios- Monthly data" that comprises the collection of regionalized climate scenarios of the National Climate Change Adaptation Plan (OECC-MAPAMA), the main climate change estimated projections conclude the following (Herrero A & Zavala MA, editors (2015)):

- Maximum temperature. All the projections show a progressive increase in the maximum temperatures during the XXI century, faster in the SRES highest-emissivity scenario (A2) and slower in the lowest-emissivity scenario (B1). In this way, for the end of the century, when the increases are higher, it is probable that the variation of the average value for the maximum temperature for the last two decades with respect to the reference value (1961/2000) is between 3.8ºC and 5.8ºC for the high-emissivity scenario (A2) and between 2.1ºC and 3.3ºC for a low-emissivity scenario (B1). The maximum summer temperatures will undergo greater changes, between 3.4ºC and 6.7ºC, while the summer ones will experience less changes, between 2.1ºC and 4.0ºC, both with respect to the medium-high-emissivity scenario (A1B).
- Heat waves. The maximum length of heat waves will progressively increase during the century. This increase will be faster in the in the inner area of the South-east quadrant in the Peninsula.
- Minimum temperature. All projections show a progressive increase during the XXI century. It is probable that the change of the average value of the minimum temperature in the mainland Spain for the last two decades is between 2.8ºC and 4.3ºC for the highest-emissivity scenario (A2) and between 1.6ºC and 2.5ºC for the lowest-emissivity scenario (B1). The changes are greater for the summer months (between 2.5ºC and 4.6ºC) and lower in the winter months (1.6ºC and 3.4ºC) and spring for the medium-high-emissivity scenario (A1B).

- Rainfall. The relative change in the average rainfall in the 2081/2100 period compared to the reference period is between -10% and -27% for the A2 scenario and between -2% and -17% for the B1 scenario. In averaged absolute terms for the whole Peninsula, the decrease in the annual accumulated rainfall can reach 20 mm/month. The rainfall evolution shows higher discrepancy and uncertainty regarding its possible evolution in the XXI century. In general terms, it shows a tendency towards a greater reduction in the lowest latitudes and, in percentage terms, it is greater in summer months than in winter months. There is a slight reduction in the number of days with rainfall, an increase in the maximum length of dry periods and an increase in the rainfall in the highest percentiles (less rainfall but more intense). Regarding the meteorological drought, an increase of 15 to 20 days is observed in the maximum number of consecutive days without rainfall in mainland Spain.

The Spanish National Adaptation Plan (PNACC), adopted in July 2006, is the reference framework for the development of adaptation policies in Spain. It promotes the coordination between all Public Administrations that deal with the assessment of impacts, vulnerability and adaptation to climate change. It includes all sectors and natural resources acknowledged as potentially affected and is developed through specific Work Programmes. The Plan was adopted by the Council of Ministers after a wide consultation process that included the main coordination and participation bodies dealing with Climate Change in Spain: the National Climate Council (CNC), The Coordination Commission of Climate Change Policies (CCPCC) and the Environmental Sector Conference. The process engaged representatives from public administrations, non-governmental organizations and other stakeholders.

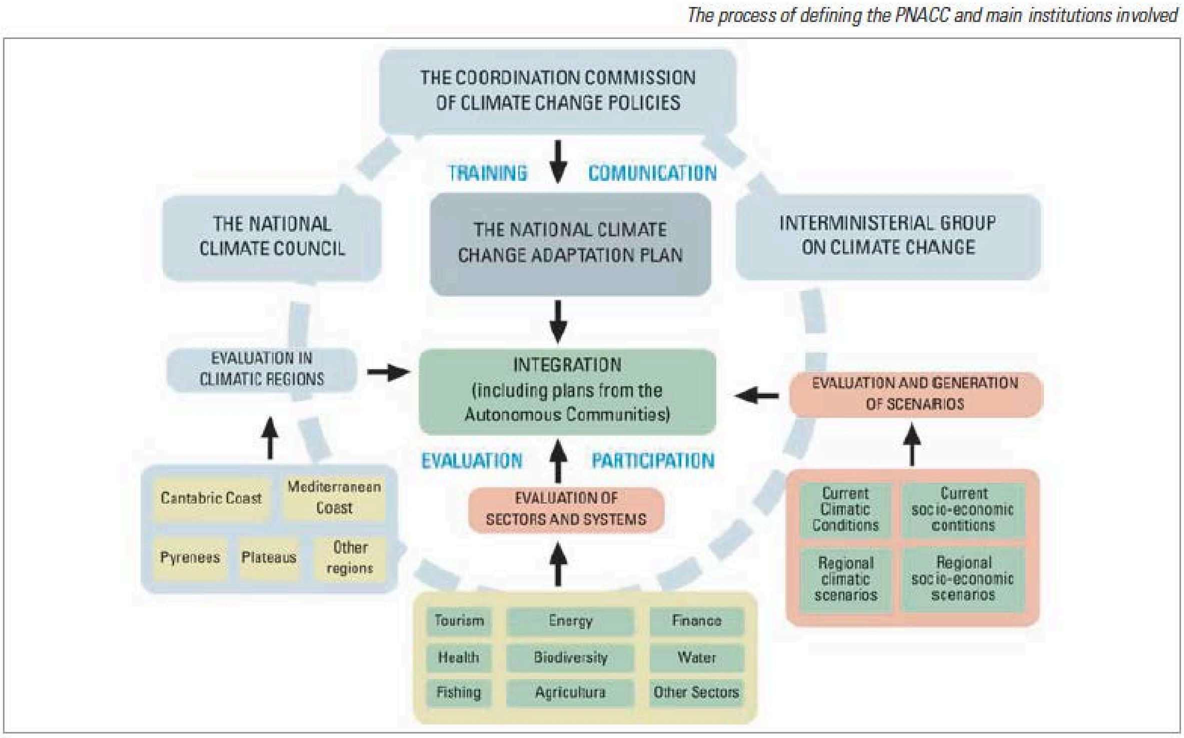


Figure 35: Process of defining the PNACC and main institutions involved. Source MAGRAMA

The Spanish Climate Change Office (OECC in Spanish) within the Ministry of Agriculture, Food and Environment, coordinates, manages and follows up the implementation of the PNACC and its Work Programmes. The Plan's general objective is to mainstream climate change adaptation into the planning and management of vulnerable sectors and systems in Spain

Sub national level

At regional level, the vast majority of the Spanish Autonomous Communities have already adopted their adaptation strategies, plans or actions. Most of them have considered adaptation within general climate change strategies, frameworks or plans in the form of programmes, measures or actions, whereas some others have developed their own Adaptation Strategies or frameworks. The lines of work in which the Autonomous Communities have developed their strategies and plans are coherent with the National Adaptation Plan and its work programmes.

In general terms, regional frameworks relating adaptation to climate change are focused on:

- Generation and analysis of knowledge: They have covered most of the sectors identified by PNACC: Biodiversity, water resources, forests, agriculture, soils/desertification, human health, tourism…
- Systematic climate observations.
- Research of the climate system and climate change.

The PNACC sets out the expected effects of climate change over agriculture and livestock in Spain. In general terms it is said, that these effects will not be uniform; while they will be negative in some Spanish regions, they might be beneficial in some others:

- The negative effect of high temperatures and lower precipitations may be compensated in some cases by higher photosynthetic rates, due to the increase of CO_2 in the atmosphere. In addition, softer winter temperatures will permit higher yields, compensating for the losses of other seasons. In other cases, this effect will diminish the impact bit it will not be enough to fully offset it.

- Irrigation needs will increase in certain regions.
- The distribution and impact of pests and diseases will shift, causing new effects to the crops important for the agricultural sector, and therefore for the Spanish economy.
- The effects of climate change on livestock are still uncertain, but significant impacts on animal health are expected.

The PNACC is being developed through the different work programmes, which activities are prioritized and structured. Some results of these work programmes for agriculture sector are:

- Report "Impacts of the agrarian sector in Spain"
- Framework Cooperation Agreement between the OECC, UPM, General Secretariat of Agriculture, Food and Environment through CEIGRAM for the promotion of I+D+I activities in the field of mitigation and Impact assessment, vulnerability and adaptation to climate change in agriculture, livestock and other sectors related.
- Global Research Alliance on Agricultural Greenhouse Gases (http://globalresearchalliance.org/)

Agriculture is one of the sector's considered in the PNACC-WP3 to address adaptation actions during the period 2014-2020. It is specifically included in the first axe of action: (i) sectorial impacts and vulnerability assessments, where it is planned:

- Review, synthesis and evaluation of existing knowledge.
- Establishment and development of frameworks for collaboration in the field of agricultural insurance.
- Impacts and adaptation to climate change on major areas and Agricultural crops in Spain, including irrigated agriculture and its demands of water.
- Impacts and adaptation to climate change on:
    - zones and cattle herds in Spain
    - aquaculture in Spain.
    - Spanish agri-food industry.
    - agricultural insurance in Spain.
    - fishing activity in Spain.
- Development of methodologies for analyzing costs and benefits of Adaptation, and application in pilot areas or areas of the sector.
- Development of a methodological guide for the integration of adaptation to climate change in the Spanish business strategy of the agri-food sector.
- Indicators of climate change in the sector

Further information at http://climate-adapt.eea.europa.eu/countries-regions/countries/spain

4.2.2 Climate Tool or services

The production of regional climate change scenarios for the Spanish territory throughout the 21st century represents a key element of the PNACC. AEMET is responsible for coordinating this PNACC component, making them available in AEMET's climate services website for all those interested in climate change projections for Spain. In the initial phase of PNACC, a first generation of regional projections was produced in 2007, based on the IPCC-TAR scenarios, together with the report "Generation of Regional Climate Change Scenarios for Spain". The second phase has produced the collection of projections 'Scenarios-PNACC 2012', from the IPCC-4AR scenarios. They have been generated from different GCMs and scenarios, using both dynamic and statistical methods. Additionally, a more friendly and user-focused set of products has been elaborated, based on the results of a producers-users workshop held in 2011.
A third collection of regional climate change scenarios for Spain derived from IPCC AR5 scenarios has been produced together with a friendly tool tailored to user needs, in order to improve the products of climate projections and services: http://adaptecca.es/escenarios/. The main aim of this tool is to facilitate consultation of regional climate change projections for Spain during the XXI century, carried out by the State Agency of Meteorology (AEMET) following statistical regionalization techniques. The offered products come from projections with daily data generated using statistical regionalization techniques based on global projections of the Fifth

Assessment Report (AR5) of the IPCC (Intergovernmental Experts on Climate Change). These projections contemplate three of the emission scenarios (RCP 4.5, RCP 6.0, RCP 8.5) and collect data over the period 2015-2100 of: Maximum and minimum temperature for 360 thermometric and precipitation stations and for 2092 rainfall stations. The set of data that the application Scenarios processes sum more than 6,000 million. The application allows consultations on: precipitation projections, maximum temperature, minimum temperature, no warm days, no warm nights, no days of frost, no rainy days, duration of heat waves and duration of the dry period during the XXI century (in relation to the reference period 1961-1990). Also, the Scenarios application allows to generate graphic products for an area or territory chosen by the user (municipality, province, river basin, etc.), which are processed by the processing of the data of the stations included within the selected area and group all available projections. The interpretation of the data must take into account the representativeness of the whole of stations considered in each consultation, in terms of number of stations and distribution of them, applying a precautionary principle when considered areas where the stations are few or the nearby. The projection data are indicative in terms of trends and their use in terms of reliability and resolution is not comparable to that of the data observed for short- and medium-term predictions. Climate projections are based on results from computer models that imply simplifications of actual physical processes that are not currently fully understood. The Scenarios application is a tool that will be updated as new data are generated and information on projections of new indicators are demanded by the users.

4.2.3 Projects dealing with adaptation in agriculture

Since a few years, some studies are available in Spain that helps to quantify the agricultural impacts of climate change. A research platform, managed by Spanish Office of Climate Change, from the Ministry of Agriculture, Fisheries, Food and Environment (OECC-MAPAMA) and named Adaptecca, is specifically devoted to climate change impacts and adaptation: it gather a platform for exchange and consultation of information on adaptation to climate change in Spain. www.adaptecca.es

MACSUR: Modelling European Agriculture with Climate Change for Food Security is an European project that brings together the excellence of research in modelling grasslands, livestock, crops, farms, and agricultural trade in order to improve the modelling of climate change impacts on European agriculture and in order to illustrate to political decision makers how climate will affect regional farming systems and food production in Europe. Different Spanish researchers collaborate in this Hub.

Cereals is one of the main crops in Spain, and climate change will affect considerably these crops ought to water stress, heat stress and droughts. There are many studies regarding adaptation options for these crops realised by several researchers as Ana Iglesias, Margarita Ramos or Tudela.

Irrigated and rainfed agriculture already facing water scarcity and extreme temperatures, will be among the most affected ones. LIFE Project ClimAgri tries to demonstrate the viability of management systems based on the integration of measures for the mitigation of climate change and the adaptation of irrigation crops thereto in the Mediterranean Basin.

Agroforestry is a relevant sector in southern countries as Cyprus, Greece, Malta, Italy, Portugal, Slovenia and Spain where the surface devoted to these both in terms of surface and UAA share (see Figure 32), and for the EU it accounts for up to 8.8% of the UAA. The AGFORWARD project that pomotes agroforestry practices in Europe that will advance rural development i.e. improved competitiveness, and social and environmental enhancement, has produced several studiess and reaserchs about adaptation to climate change of this systems. And the LIFE "Montado & Climate: A need to Adapt" will introduce innovative adaptation technologies in dehesas and montados of Spain and Portugal.

For vineyards and wine production, Resco et.al have explored adaptation choices for grapevine regions in Spain and adaptation policy options.

Regarding intensive Livestock, an interesting project is OptiBarn, European research project with the aim to develop regional, sustainable adaptation strategies for dairy cow husbandry.

Table 22: List of projects dealing with adaptation for the agricultural sector in Spain

Project	Farming system	Scope (national, regional)	Contact (name, email, web)
Modelling European Agriculture with Climate Change for Food Security (MACSUR 1 and 2) http://macsur.eu/ 2013-2019 in Spain	Cereals, vineyards, livestock	European (Knowledge hub of 70 institutions from 18 countries)	Margarita Ruiz-Ramos Margarita.ruiz.ramos@upm.es
"Impacto y adaptación de sistemas agrícolas de la zona Centro de la Península al cambio climático"PAI08-0009-4676 2008- 2009.	Cereals	Regional: Vice consejería de Educación y Ciencia de la Junta de Comunidades de Castilla-La Mancha	Margarita Ruiz-Ramos Margarita.ruiz.ramos@upm.es
Generación de escenarios probabilísticos de impacto y adaptación al cambio climático en la agricultura de la zona Centro de la Península. Herramienta de Soporte Científico a la toma de decisiones, v. 2" PEII10-0248-5680 2010-2013	Cereals	Regional: Vice consejería de Educación y Ciencia de la Junta de Comunidades de Castilla-La Mancha	Margarita Ruiz-Ramos Margarita.ruiz.ramos@upm.es
BASE EU research project "Bottom-Up Climate Adaptation Strategies Towards a Sustainable Europe" (BASE) supports action for sustainable climate change adaptation in Europe	Rice in a coastal Wetland. Doñana	European, Regional: Spain	Ana Iglesias ana.iglesias@upm.es http://base-adaptation.eu/about-base
OptiBarn. Optimised animal specific barn climatisation facing temperature rise and increased climate variability	Livestock dairy cattle intensive	European. In Spain: Valencia	http://www.optibarn.eu/ Fernando Estellés. Universitat Politécnica de Valencia. feresbar@upv.es
AGFORWARD (AGroFORestry that Will Advance Rural Development)	Dehesas. Extensive LivestocK	European Southwest of Spain	Gerardo Moreno. https://www.agforward.eu/
'Montado & Climate: A need to Adapt'	Dehesas/ Extensive Livestock	Spain and Portugal	ambiente@adpm.pt http://adpm.pt/o-que-fazemos/projetos/life-montado-climate-a-need-to-adapt/
LIFE ClimAgri	Irrigated crops	Mediterranean (Spain, Italy, Portugal, Greece)	Asociación Española de Agricultura de Conservación. Suelos Vivos info@agriculturadeconservacion.org www.climagri.eu
LIFE ADAPT2CLIMA		Mediterranean	adapt2clima.eu; cgiannak@meteo.noa.gr

4.2.4 Agro-climatic grids

Spanish agricultural production accounts for 12.1 % to the EU farming production. The most relevant sectors, contributing to 50 % of national agricultural production, are fruit and vegetables, vineyards, olive groves and cereals. Cereal production occupies up to 40 % of the Spanish farmland and ¾ parts of the arable land. Permanent crops, which are not relevant on other EU countries, account for approximately one third of the agrarian surface. However, these figures are not aligned with the economic weight these subsectors have. In that sense, irrigated areas (especially for vegetable production and industrial crops, and some permanent crops) concentrate the economic benefits. Cereal productivity, in comparison with EU production, is strongly related to water availability and optimal soils. Rainfed winter cereals, with significantly lower yields than in Central Europe, dominate in Spanish cereal production. Spain is the country with the largest vineyard area, almost 1.2 million hectares, 14 % of the World area. Production however is highly variable due to geographical and climate conditions, as well as to large interannual variability. Traditional rainfed vineyard is now co-existing with new irrigated plantations (expansion of 40 % in the last 15 years) with current environmental problems (groundwater overuse and salinization) and expected in the future (irrigated vineyards in areas where the climate will be changing). Livestock contributes to 40 % of the National production, with very diverse livestock production systems. Approximately 30 % of national territory (50 Mha) is farmed or used for pastures.

4.2.4.1 ARABLE CROPS

Table 23: Agro-climate grid for arable crops in Spain

Arable crops	Climate risks	Climate opportunities
Winter cereals (mainly wheat and barley)	**Water stress** Increase drought in spring and summer **Changes in phenology** Shortening of crop cycle, sowing dates change and earlier maturity **Heat stress** Pronounced warming and decreased precipitation in spring and summer Increased heat risks during critical times of the crop cycle Loss of winter cold needed by some varieties **More frequency of extreme events** Increased probability of lethal temperatures in critical moments More interseasonal variability Increased probability of heavy precipitations **Crop health** More pest/diseases or new ones **Farm management** Higher energy consumed in irrigation Complete loss or degradation of farming soils **Ecosystem services** Reduction of ecosystem services or changes (pollination services, biodiversity loss, occurrence of invasive species)	**Higher photosynthetic rates** Increasing atmospheric CO_2 increases photosynthesis rates **Higher productivity in temperature -limited areas** Warmer winters will positively affect productivity, if water is ensured - in areas where winter temperature limits growth- **Better conditions harvesting** Proportion of suitable harvest days in June remains high or increases in MDN and MDS **Better sowing conditions** Autumn sowing conditions improves substantially in MDM
Maize	**Water stress** Increasing water demand Number of days with water deficit increases in spring Profound increase in summer drought duration **Changes in phenology** Decrease in the number of suitable days for sowing Sowing dates moved forward **More frequency of extreme events** Extreme Tmax events during grain filling **Crop health** More pest/diseases or new ones **Farm management** Higher energy consumed in irrigation Complete loss or degradation of farming soils **Ecosystem services** Reduction of ecosystem services or changes (pollination services, biodiversity loss, occurrence of invasive species)	**Less water needs** The irrigation needs of maize will be smaller in the future climate, in spite of the temperature increase, due to the shortening of the crop cycle
Vegetables	**Water stress** Number of days with water deficit increases in spring Profound increase in summer drought duration Higher demand for water, with probability of lower quality of irrigation water and suffering from marine intrusion into aquifers and from nitrate pollution **More frequency of extreme events** Higher frequency of heat waves, heavy precipitation, cold waves, hail storms, etc. **Crop health** More pest/diseases or new ones **Farm management** Higher energy consumed in irrigation Complete loss or degradation of farming soils **Ecosystem services** Reduction of ecosystem services or changes (pollination services, biodiversity loss, occurrence of invasive species)	**Wider variety of crops** Longer frost-free periods (earlier date for last frost). May entail a wider variety of legumes during winter but probably balanced with shorter growing season overall (=shifting growing periods and phenology but not enriching the potential)

Near future (about 2030):

The climate trends described and the agronomic consequences identified above will be intensified in the near future. Yield reduction, degradation of agricultural conditions and loss of farming areas will be the main overall consequences, due in most cases to high temperatures and hydric stress. Extreme events will also play a very important role, especially in farming systems which productivity is low and irregular (rainfed cereals), as the average competitiveness of the farms will probably decrease to unsustainable levels. For some irrigated crops, water availability will be critical for its future, but water scarcity due to climate change and other related issues (water demand for other sectors, National priorities, etc.) will have a strong influence.

4.2.4.2 PERMANENT CROPS

For vineyards, very detailed projections for each Designation of Origin in Resco et al., 2016.

Table 24: Agro-climate grid for permanent crops in Spain

Permanent crops	Climate risks	Climate opportunities
Vineyards	**Heat stress** Over-ripening, leading to the need of growing new varieties (rootstocks changes) to avoid wines with no commercial interest Need to introduce warmer climate varieties that may not be supported with current normative (Designations of Origin or similar quality labels) **Water stress** Irrigation might become mandatory, and a reduction of humidity in the North that could favour ripening and reduce diseases, but also increase irrigation needs to prevent frequent stress **More extreme weather events** Extreme temperatures during the growing season (above 35ºC) more frequent. **Changes in wine quality/characteristics** Grapevines with low aroma content. Overall, the red varieties also could be at risk of becoming a relatively light colour **Crop health** More pest/diseases or new ones **Farm management** Higher energy consumed in irrigation Complete loss or degradation of farming soils **Ecosystem services** Reduction of ecosystem services or changes (pollination services, biodiversity loss, occurrence of invasive species)	**Vineyard expansion in northern areas** Overall temperature increase may increase the suitability of the area to more varieties and optimal ripening
Fruit trees	**Water stress** Some irrigated fruit productions will increase the water demand. Some rainfed fruit trees (nut family) will need irrigation for competitive average yields. **Changes in phenology** Lack of cold-hours needed for blooming **Crop health** More pest/diseases or new ones **Farm management** Higher energy consumed in irrigation Complete loss or degradation of farming soils **Ecosystem services** Reduction of ecosystem services or changes (pollination services, biodiversity loss, occurrence of invasive species)	**Expansion of some species to northern areas** Warmer winters and reasonable access to water for irrigation will allow growing Mediterranean permanent crops in northern areas

Near future (about 2030):

The only positive perspective for the near future are that by 2050 the MDM will reach a Huglin Index suitable for wine production, and that some fruit production areas in the north will be able to hold new species and varieties that currently cannot be produced due to cold limitations. However, these potential benefits shall be balanced with other counterproductive effects, such as the loss of other crops currently produced or the future availability of water (in some cases).
The worst consequences will be newly established fruit and vineyard production areas in semi-arid conditions, in some cases quire recent investments that rely on irrigation for achieving competitive yields. The loss of suitable growing conditions (loss of winter, high temperatures at ripening, etc.) added to the scarcity of water, can make these new agricultural areas unsuitable in the future at the time they should be reaching their higher productivity. Long-term planning of hydrological resources as well as an appropriate agricultural strategy will be necessary to avoid such situations in critical areas.

4.2.4.3 LIVESTOCK

The influence of climate change on the livestock sector is complex due to the diversity of production systems and the multiple factors that influence the livestock sector such as the availability of water resources, soil systems or agricultural production. Additionally, effects will depend on the exploitation system, the climatic repercussions can range from intensive livestock farming systems, where environmental conditions may be more controlled, to extensive livestock farming systems that are strongly Influenced by climatic conditions.

Direct impacts

Table 25: Agro-climate grid for animals (direct impacts) in Spain

Animals	Climate risks	Climate opportunities
All	**Increase in stress level in cattle due to temperature.** Animals will not be in their optimal environmental conditions so they will consume more energy and therefore more food (Sharrow, 2014). Increase in temperatures modifies nutrition patterns because of the need to release heat produced by the energy metabolism of animals (Moreno et al., 2005) Reduction of grazing hours because of higher temperatures in a wider time during the day.(Moreno et al, 2005) Immunosuppressive and reproduction effects: increase in levels of cortisol and adrenaline and increase in the number of abortions **Livestocks health:** Advancement in appearance of the populations of parasites due to the increase of temperature and changes in the spatial distribution of these populations Higher incidence of pests and diseases due to lower mortality in winter due to rising temperatures Changes in the special distribution of populations of parasites and their vectors as new areas appear suitable for them. There will be a latitudinal displacement of species such as ticks (Boophilus microplus, Canestrini) that affect cattle Increase in the use of veterinary treatments. Possible increase of resistance	**Increase of temperature in winter:** Decrease of deaths by cold

Indirect impacts

Table 26: Agro-climate grid for animals (indirect impacts) in Spain

Fodder crops	Climate risks	Climate opportunities
Permanent grasslands	**Changes in pasture availability:** Lower quality (less legumes) in pasture due to less consistent distribution of spring rains (Gerardo Moreno, 2016) Less amount of organic matter in the soil due to an increase in the frequency and duration of the following seasons. (Plan de Adaptación al Cambio Climático del Sector Ganadero de Extremadura) **Soils impacts:** Increased risk of soil washing due to the increase in the number of extreme climatic events **Animal impact:** Reduction of the time of potential use of the pasture and, therefore, risk of overgrazing and / or infragrazing	Changes in pasture availability: Increased pasture production in autumn / winter due to increased CO_2 and temperature.
Water	Decrease of water availability from ponds.(Observatorio Extremeño CC) Lower quality and availability of water resources.	
Trees	Less acorn production due to water stress (Gerardo Moreno). Increased fire risk due to rising temperatures, reduced rainfall (Observatorio Extremeño de CC) Higher incidence of "seca"(oak decline disease) in the woodland since it is favoured by the alternation of periods of drought with periods of rain. (Gerardo Moreno)	
Winter cereals	With **warmer winters**, winter cereals needing cold conditions decrease their productivity (OECC, 2016)	**Warmer winters** will positively affect productivity, if water is ensured (OECC, 2016).

4.2.5 Spanish bibliography

Armas, C.I. 2014. Viticultura y cambio climático. Trabajo Fin de Grado. Universidad de La Rioja.

Iglesias A y Quiroga S. (2007). Measuring the risk of climate variability to cereal production at five sites in Spain. Climate Research. 34: pp. 45–57.

Iglesias A., Quiroga S., Schlickenrieder J. (2010) Climate change and agricultural adaptation: assessing management uncertainty for four crop types in Spain. Climate Research, 44: 83-94.

Gabaldón-Leal C., Lorite I.J., Mínguez M.I., Lizaso J.I., ,Dosio A., Sanchez E., and Ruiz-Ramos M., 2015. Strategies for adapting maize to climate change and extreme temperatures in Andalusia, Spain. Climate Research, 65:159-173, doi:10.3354/cr01311.

Garrido A., Rey D., Ruiz-Ramos M. and Mínguez M.I., 2011.Climate change and crop adaptation in Spain: consistency of regional climate models. Climate Research Climate Research 49, 211-227.

Garrido A., Bielza M., Rey D., Mínguez MI. and Ruiz-Ramos M., 2011.Insurance as an adaptation to climate variability in agriculture. Chapter 19 in: Handbook on Climate Change and Agriculture Mendelsohn M and Dinar A. (Eds.), Edward Elgar Publishing Ltd., ISBN10 1849801169

Ibáñez D. 2011. Efectos del cambio climático en las actividades agrarias y forestales. 2011.

Iglesias, E. et al. 2016. Assessing drought risk in Mediterranean Dehesa grazing lands. Agricultural systems.

Medida, F. 2016. Impactos, vulnerabilidad y adaptación al cambio climático en el sector agrario: aproximación al conocimiento y prácticas de gestión en España. Oficina Española de Cambio Climático. Ministerio de Agricultura, Alimentación y Medio Ambiente.

M.I. Mínguez Tudela. 2011 MINUNIMAD-CC: Minimización de incertidumbres en los análisis de impactos y adaptaciones en los sistemas agrícolas de la Península Ibérica. Herramienta de Soporte Científico para la Toma de Decisiones Políticas”. AGL2008-00385. 2009- 2011.

M.I. Mínguez Tudela. 2015. MULCLIVAR, Subproyecto ACER-AGRO, Variabilidad Climática Multiescalar. Impactos Agrícolas Y Económicos. Ii Evaluación Integrada De Riesgos Climáticos y Económicos: Adaptación De Sistemas Agrícolas En España

Mosquera-Losada, M.R. et al. 2015. Sistemas agroforestales y PAC. Ambienta.

Pérez et al. 2011. Impactos, vulnerabilidad y adaptación al cambio climático en el sector agrario aproximación al conocimiento y prácticas de gestión en España. Junta de Extremadura.

Pérez, M.A. et al. 2011. Mapa de impactos del cambio climático en Extremadura. Consejería de Industria, Energía y Medio Ambiente. Junta de Extremadura.

Resco et al., 2016. Exploring adaptation choices for grapevine regions in Spain. Reg Environ Change (2016) 16:979–993

Región de Murcia (2008). Estrategia de la región de Murcia frente al cambio climático 2008-2012.

Resco, P. 2015. Viticultura y Cambio Climático en España: Vulnerabilidad en las distintas regiones y estrategias de adaptación frente al desarrollo de nuevas políticas. Tesis Doctoral.

Rey D., Garrido A., Mínguez M.I. and Ruiz-Ramos M., 2011.Impact of climate change on maize's water needs, yields and profitability under various water prices in Spain. Spanish Journal of Agricultural Research 9(4), doi: 10.5424/sjar/20110904-026-11

Rey, D. et al., 2011. Impact of climate change on maize's water needs, yields and profitability under various water prices in Spain. Spanish Journal of Agricultural Research 2011 9(4), 1047-1058.

Ruiz-Ramos, M. et al., 2011. Impacts of projected maximum temperature extremes for C21 by an ensemble of regional climate models on cereal cropping systems in the Iberian Peninsula. Nat. Hazards Earth Syst. Sci., 11, 3275–3291.

Ruiz-Ramos, M. & Mínguez, M.I. 2010. Evaluating uncertainty in climate change impacts on crop productivity in the Iberian Peninsula. Contribution to Climate Reasearch Special 22 'Agriculture in a changing climate'. Vol. 44: 69–82.

Ruiz Ramos, M. 2009. "Impacto y adaptación de sistemas agrícolas de la zona Centro de la Península al cambio climático"PAI08-0009-4676

Ruiz Ramos, M. 2013. Generación de escenarios probabilísticos de impacto y adaptación al cambio climático en la agricultura de la zona Centro de la Península.Herramienta de Soporte Científico a la toma de decisiones, v. 2" PEII10-0248-5680

Serrada R. Et al. 2011. Impactos, vulnerabilidad y adaptación al cambio climático en el sector forestal. Ministerio de Medio Ambiente y Medio Rural y Marino.

Tao F., Rötter R.P., Palosuo T., Díaz-Ambrona C.H.G., Mínguez M.I., Semenov M.A., Kersebaum K.C., Nendel C., Cammarano D., Hoffmann H., Ewert F., Dambreville A., Martre P., Rodríguez L., Ruiz-Ramos M., Gaiser T., Höhn J.G., Salo T., Ferrise R., Bindi M., Schulman A. H. Designing future barley ideotypes using a crop model ensemble, European Journal of Agronomy, Available online 6 November 2016, ISSN 1161-0301, http://dx.doi.org/10.1016/j.eja.2016.10.012.

Trnka et al., 2014. Adverse weather conditions for European wheat production will become more frequent with climate change. NATURE CLIMATE CHANGE, VOL 4

Trnka et al., 2011. Agroclimatic conditions in Europe under climate change. Global Change Biology, Volume 17, Issue 7, pages 2298–2318.

Herder M. et al, 2015. Current extent and trends of agroforestry in the EU27. AGFORWARD (613520)

List of Spanish experts identified

- Meteorologist: J.R. Picatoste (OECC, MAPAMA)
- Agronomists: M. J. Alonso (OECC, MAPAMA); A. Iglesias (UPM);
- Crops: M. Ruiz Ramos (UPM)
- Livestock: F. Estellés (UPV); G. Moreno (UEX)
- Vineyards: V. Sotés (UPM)
- Agrarian Insurance: JC. Cuevas (Agroseguros) J.M. García (ENESA)

5 Northern Climate Zone

5.1 OVERVIEW

The share of agricultural holdings (4 %) and utilized agricultural area (6 %) is relatively small in the Northern climate zone compared to other climate regions in Europe. Agricultural area is mainly used as arable land (81 %) and different grasslands (18 %), permanent crops cover less than 1 % of UAA.

Table 27: Main agricultural figures (Eurostat 2013) for EU-28, the Northern climate region and the share of Estonia within the Northern climate region

	Total UE-28	**Northern**	**Estonia**
Number of holdings (1 000)	**10 841**	394	19
%	**100 %**	4 %	5 %
Utilized agricultural area (1 000 ha)	174 351	10 983	958
%	100 %	6 %	9 %
% Arable land / UAA	60 %	81 %	66 %
% Permanent grassland and Meadow / UAA	34 %	18 %	34 %
% Permanent crops / UAA	6 %	0 %	0 %
Labour force (1 000 AWU)	9 345	307	22
%	100 %	3 %	7 %
Average area of holdings (ha)	16,1	27,9	49,9
Livestock Units (1 000 LSU)	130 320	4 492	310
%	100 %	3 %	7 %
Standard Output (million EUR)	331 568	12 067	676
%	100 %	4 %	6 %

Northern: Estonia, Finland, Latvia, Lithuania and Sweden

5.2 ESTONIAN FOCUS

5.2.1 Climate trends & National Adaptation Strategy

Estonian National Climate Change Adaptation Strategy (Keskkonnaministeerium, 2016) was initiated in 2013 and the draft plan together with the operational programme was finalized in spring, 2016. The general purpose of the Strategy was to achieve preparedness and capacity to cope with the consequences of the climate changes in eight priority sectors. Bioeconomy, incl. agriculture, forestry, fisheries, game and hunting, tourism and peat production was one of those sectors.

The proposal for the Estonian National Climate Change Adaptation Strategy and the operational programme was developed in line with regional fine scaling of the global climate projections CMIP5 based on the two global climate change scenarios – RCP4.5 and RCP8.5 through 2100 for the newest Assessment Report (AR5) prepared by the Intergovernmental Panel on Climate Change (IPCC) (Luhamaa *et al*. 2014). Although not as extreme as in many other regions of the world or European Union, several significant changes have been forecasted for Estonia, during the 21th century. Temperatures rise in Estonia faster than the global average since the second half of the 20th century (Figure 36). Therefore, persisting winter ice and snow cover are expected to disappear; summers become longer with growing risk of heatwaves and drought; several natural processes are expected to change e.g. plant growth, adaptation of non-native species incl. introduced plant pests and pathogens; waterlogging of the land inhibits the use of mechanical devices in harvesting; seasonal energy demand peaks are predicted to change etc.

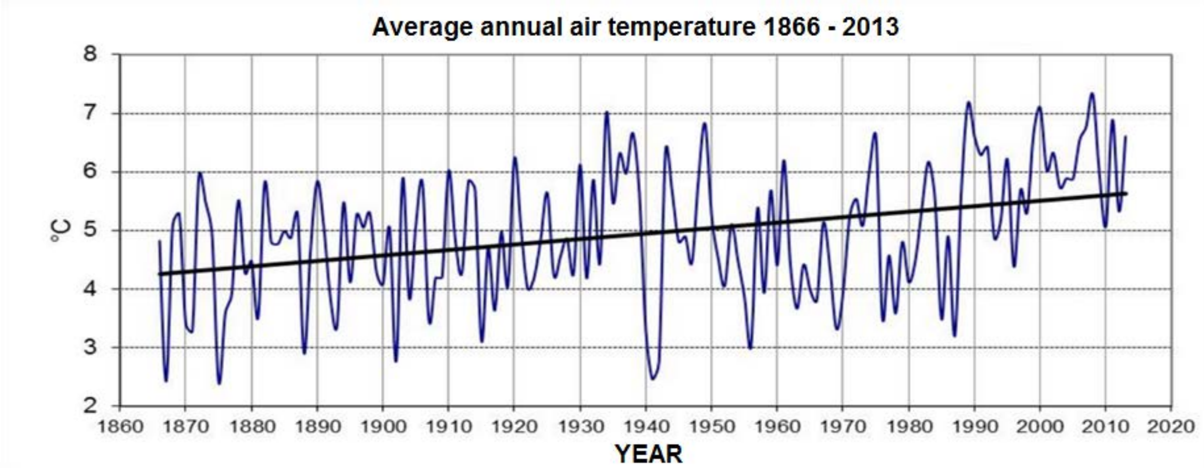


Figure 36: Annual average air temperatures in Tartu-Tõravere weather station, South-East Estonia (Luhamaa et al. 2015).

According to the climate scenarios projected by Luhamaa et al, (2014), in 2040 – 2070, the winter becomes warmer by 2.3 – 3.1 °C and spring by 2.4 - 3.4 °C, whereas summer and autumn temperatures are rising only about 1.6 - 2.2 °C. In monthly comparison, the highest temperature rise shall presumably occur in March, since this is favoured by the lack of snow cover in spring and resulting earlier increase of the soil temperatures. Thus, we may calculate, that the sum of active temperatures (>10 °C) (standard mean in Estonia btw 1700 – 1900 °C (Aruksaar *et al*, 1964)), would rise for about 250 °C per vegetation period. In other words, the average summer temperatures are not about to increase a lot, but there will be more heat- and drought periods. The models project the increasing amounts of extreme convectional rainfalls that may cause local flooding after thunderstorms: the probability of their occurrence increases in summer by 124 - 165 % for the next 50 year with 0.54 % of the probability at a random geographical location in Estonia in any of the day from June to August (Luhamaa et al, 2014). The models predict significant decrease of the snow cover by the end of 21-th century: as in April, the snow cover used to persist on average 1 - 6 days in the control period 1971-2000, both the RCP4.5 and RCP8.5 show only minor probability of snow in April by the end of the century (Luhamaa et al, 2015). Winter and partially also spring wind velocity gradient could rise due to increasing number of cyclones from the Atlantic Ocean over to Estonia.
In 2015, a project BioClim "Adapting to climate change in Estonia: current state, impact assessment and adaptation measures" was carried out working paper on national climate adaptation strategy and action plan for natural environment and bioeconomy were developed. Climate change impacts were analysed and existing adaptation measures were recorded by risks, vulnerabilities and climate change impacts on the environmental and economy sectors. Finally, suggestions were developed for national adaptation measures, considering four time periods: until 2020; until 2030; 2021-2050; and 2051-2100.
The change of species composition, thawing of soil in winter and loss of soil fertility have been assessed to be the most significant climate change impacts for agriculture (Kaasik et al, 2015). Estonia is situated in the climatic area, where projected changes may introduce certain opportunities for the agriculture, eg. extension of vegetation period (Figure 34). However, highly fluctuating weather conditions may also cause significant instability in crop yield and quality (Keskkonnaministeerium, 2016). In general, it has been assumed that major impact of climate change is predominantly positive factors affecting arable cropping and pastures (Kallis et al,

2014), nevertheless, the BioClim project has identified several vulnerabilities to become apparent in 30-year perspective.

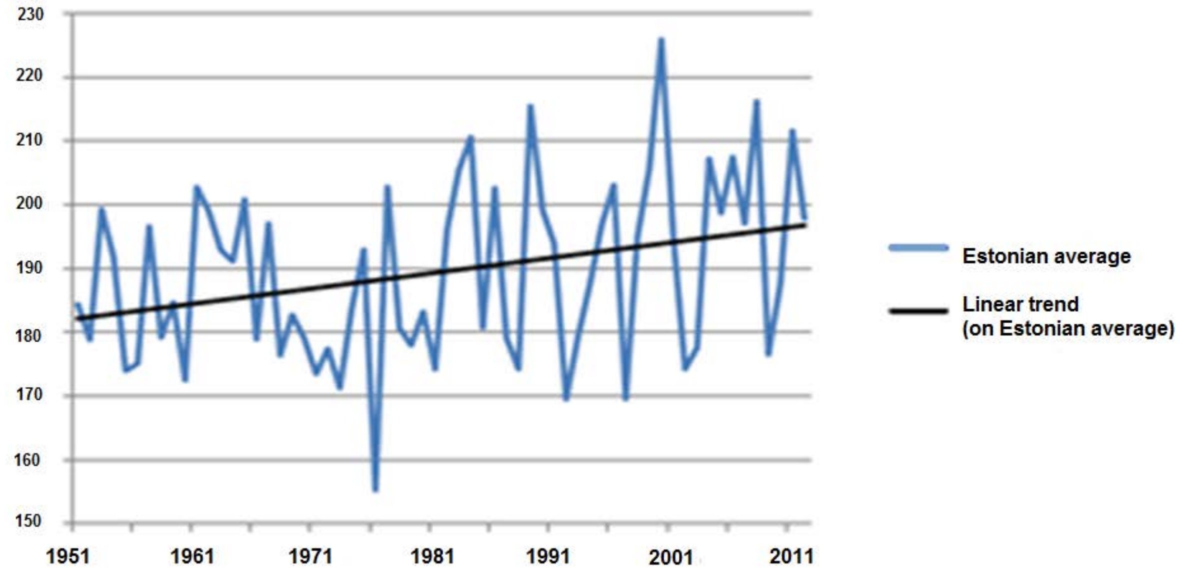


Figure 37: Average duration of the vegetation period from 1951 – 2012 in Estonia (Viru, 2014)

Above all, Estonian agriculture is going to be affected by rising average temperatures and thermal variability. Other major abiotic drivers of climatic challenges are predicted increase in atmospheric CO_2, changes in precipitation and exposure to extreme weather and climatic events. Weather-related gains may also be driven mostly by temperature in various agricultural sectors. However, certain benefits may be encountered because of the increasing CO_2 concentration, which affects plant physiology and reducing amount of UV-radiation in northern high-latitude areas, which would increase the efficiency and competitiveness of microbial pesticides for biocontrol. Many challenges inherent to plant production would affect also animal husbandry primarily via forage and roughage biomass.
Most significant impacts of climate change may become disturbances and shocks due by abiotic but also biotic processes. On the other hand, the complex of weather events could end up leading to the introduction of a new, alien environmental status which is extraneous to the agricultural production. Crop failure due to climatic factors can vary locally depending on the soil conditions, but generally vulnerability of the agricultural producers arises on account of lower economic competitiveness.
European Climate Adaptation Platform provides more information about Estonian adaption strategy, policy and related topics:
http://climate-adapt.eea.europa.eu/countries-regions/countries/estonia

5.2.2 Climate Tool or services

The main climate tool available in Estonia is the Estonian Weather Service (http://www.ilmateenistus.ee/?lang=en). The data is available in national level. It publishes data and climatological information on weather observations and events, climate normals and records. About 20 indicators depending on station are recorded: max/min/average temperature; precipitation; RH; wind speed and direction; Temp on soil surface etc.

5.2.3 Projects dealing with adaptation in agriculture

The matter of adaptation to climate change in spatial planning has been assessed in the project "ASTRA – Developing Policies and Adaptation Strategies to Climate Change in the Baltic Sea Region" (http://www.astra-project.org) 2005 - 2007. The main objective of the ASTRA project was to assess regional impacts of the ongoing global change in climate and to develop strategies and policies for climate change adaptation. Estonian contributors were: Tallinn Pedagogical University, Institute of Ecology, Tartu Department; Geological Survey Of Estonia (EKG), the coordinator Are Kont, Tallinn University, Estonia.

BaltADAPT (http://www.baltadapt.eu), a project implemented 2010 - 2013 was focussed on Preparation of a Baltic Sea Region-wide climate change, adaptation strategy and action plan with focus on the Sea and coastal areas. The Estonian partner was represented by Andres Kratovitš, University of Tartu, Estonian Marine Institute.

The BaltCICA (http://www.baltcica.org), a project „Climate Change: Impacts, Costs and Adaptation in the Baltic Sea Region (2009 – 2012) was designed to focus on the most imminent problems that climate change is likely to cause in the Baltic Sea Region. The BaltCICA project with local and regional partners was adressing regions and municipalities to cope with a changing climate. Estonian partners in the Geological Survey of Estonia (EGK) were represented by V. Petersell, S. Suuroja, T. All and J. Kivisilla.

BalticClimate, (http://www.balticclimate.org) "Baltic Challenges and Changes for local and regional development generated by Climate Change" (2009 – 2012), was targeting mainly small and medium sized cities and rural areas in all Baltic Sea region countries to support their development. The project aimed to identify how the climate change will also present opportunities and chances and not only obstacles for the development of municipalities and regions when they are accounting for climate change information in their long term strategies and planning. The partners from Estonia were Harju county government, Rapla County Government, Harju Public Transport Centre, Saku, Kehtna and Kohila Municipalities. WP 5 Climate Change BSR local and regional applying ICT Toolkit was coordinated in Estonia by P. Kuldna, the Stockholm Environmental Institute Tallinn Centre (SEIT)/EE.

BaltClim, (http://www.bef-de.org/index.php?id=52) "Local and regional strategies on climate mitigation and adaptation in the Baltic states" (2011 - 2013) was to support the Ministries of Environment in developing adaptation strategies to climate change by elaborating a road map and a background paper which outlines the problems and barriers and options for actions on the way to national adaptation strategies in the target countries. The Estonian partner was Baltic Environmental Forum (BEF) represented by L. Remmelgas, S. Oisalu and The Ministry of Environment represented by R. Jakobi.

Table 28: List of projects dealing with adaptation for the agricultural sector in Estonia

Project	Farming system	Scope (national, regional)	Contact (name, email, web)
PA1-RUP-018 "Agrometeorological forecasts and surveys (1.01.2015−31.12.2018)"	Arable	National	Jüri Kadaja
ES1106 "Assessment of EUROpean AGRIculture WATer use and trade under climate change (EURO-AGRIWAT) (18.04.2012−17.04.201	Arable	National	Jüri Kadaja
Estonian Crop Innovation cluster	Arable	National	Kaido Väljaots
616215780025 "Cropping and development of high-protein seed cultivation of soybean varieties suitable for Estonian condition. (2.02.2016−31.12.2017)"	Arable	National	Lea Narits
PA1-RUP-011 "Improving soil conservation and resource use in organic cropping systems for vegetable production through introduction and management of Agro-ecological Service Crops (1.02.2015−31.01.2018)"	Arable	National	Kalvi Tamm

5.2.4 Agro-climatic grids

The Output value of Estonian agricultural industry was 935,1 million EUR in 2015 of which crop output was appr. 50 % (Maanso, 2016). In 2016, field crops were grown on 673,000 hectares of which more than half was used for cereals (Figure 38). Winter wheat accounted for 28 %, rye for 4 %, spring barley for 37 % and spring wheat for 21 % of the total sown area of cereals in 2015. Rape and turnip rape seeds were harvested from 70,800 hectares and potatoes from 5,800 hectares. Area of open-field vegetables amounted to 3,100 hectares and apple plantations accounted for nearly a half of the area of orchards and berry plantations (6,600 ha).

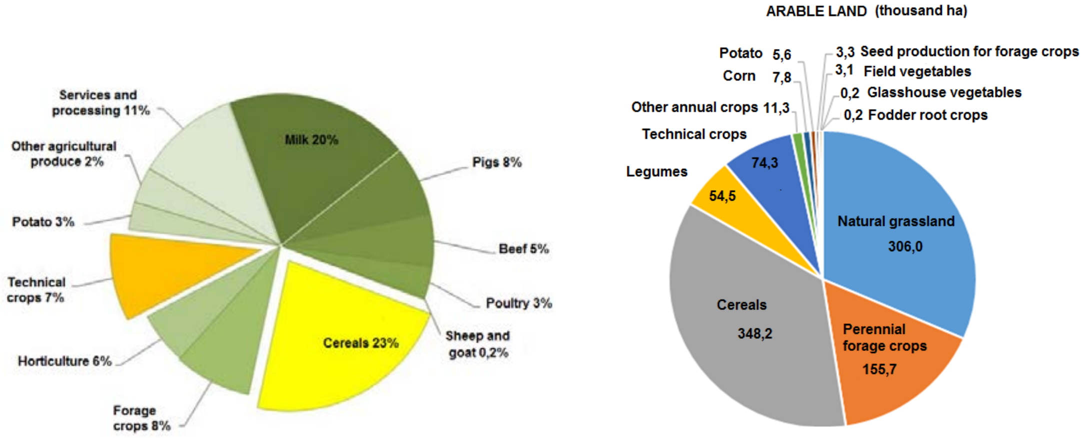


Figure 38: Share of Estonian agricultural sectors by produce value in 2015 (left) and arable land use (thousands ha) in Estonia in 2016 (right). Sources: Statistikaamet, Lauringson, E. 2016.

The number of cattle in Estonia was 256,200, including 90,600 dairy cows in 2015. Pigs numbered 304,500, sheep and goats 90,900 and poultry 2.1 million. The average milk production per cow has been growing year by year and in 2015 it amounted to 8,442 kilograms.

5.2.4.1 ARABLE CROPS

The information in the tables below is mainly collected in discussions during expert consultations with Board of Experts and from the intermediate report of BioClim (Kaasik et al, 2015) project, if not cited separately.

Table 29: Agro-climate grid for arable crops in Estonia

Arable crops	Climate risks	Climate opportunities
All crops	**Elevated temperatures and/or drought** (water deficit) prior to germination, tillering, heading or at grain filling may cause direct yield loss or quality loss. **Excess water -** longer periods of precipitation July-Aug (pre-harvest period) may cause severe quality loss. **Excess water -** Heavy rains (at heading or grain-filling) may cause lodging, direct yield loss and may interrupt with mechanical harvesting due to waterlogging throughout the pre-harvest period. **Elevated temperatures and/or drought** (water deficit) prior to heading or at grain filling may cause direct yield loss or quality loss.	Higher yield potential, higher quality in optimal conditions
Winter Wheat	**Higher temperatures and precipitation level November – March** Highly fluctuating winter conditions with warm-cold spells and liquid precipitations are likely to cause overwintering damage incl. overwintering diseases. **Higher temperatures in winter** cause lack of snow cover. Common frosts (< -25 °C) may become critical for overwintering. **Increased abundance of pests and diseases** - higher pest	The crop is preferred in heavy (clay/lime) soils (Older, 1999). Yield max. 10,5 t/ha The temperature increase may cause higher grain quality due to higher protein content in more arid climate.

	pressure, introduction of new emerging pests and pathogens may result in direct and indirect crop losses. **Water deficit** - lack of precipitation in tillering phase (spring drought after melting of snow) may result in a significant yield loss.	
Winter Rye	**Higher temperatures and precipitation level November – March** Highly fluctuating winter conditions with warm-cold spells and liquid precipitations are likely to cause overwintering damage incl. overwintering diseases. **Increased abundance of pests and diseases** - higher pest pressure, introduction of new emerging pests and pathogens may result in direct and indirect crop losses. **Excess water -** Heavy rains May – July (at grain-filling) may cause lodging, direct yield loss and may interrupt with mechanical harvesting due to waterlogging throughout the pre-harvest period. **Elevated temperatures:** as rye is an early flowering crop, and since the onset of the vegetation period tends to shift into an earlier date, flowering crop may be exposed to late frosts (**increase in extreme weather events)** with damaging consequences.	The most cold-tolerant crop in winter (-35 °C, except in certain hybrid cultivars), less sensitive to acidic soil conditions than other cereals (Older, 1999). Preferred crop in light soils, as overwintering damage is more severe in heavy soils (Older, 1999). (Yield max. 10,4 t/ha) Increasing yield potential if the average temperatures should rise. Earlier development in spring when the onset of the vegetation period shifts into an earlier date.
Winter Barley	**Higher temperatures in winter** cause lack of snow cover. Mild frosts (< -15 °C) may become critical for overwintering. **Higher temperatures and precipitation level November – March** Highly fluctuating winter conditions with warm-cold spells and liquid precipitations are likely to cause overwintering damage incl. overwintering diseases. **Increased abundance of pests and diseases** - higher pest pressure, introduction of new emerging pests and pathogens may result in direct and indirect crop losses. **Water deficit** - lack of precipitation in tillering phase (spring drought) may result in a significant yield loss.	Perspective in yield (max 12.5 t/ha); good (early) precrop for other winter crops to extend the harvest window, since it ripens 7-8 days prior to winter wheat. Higher quality, in comparison with the summer barley, which is why it is more suitable for beer production in comparison with the summer barley (Tõnisson, 1964). Elevating temperatures may result in increasing quality.
Winter rapeseed	**Higher temperatures and precipitation level November – March** Highly fluctuating winter conditions with warm-cold spells and liquid precipitations are likely to cause overwintering damage incl. overwintering diseases. **Higher temperatures in winter** cause lack of snow cover. Common frosts (< -20 °C) may become critical for overwintering. **Increased abundance of pests and diseases** - higher pest pressure, introduction of new emerging pests and pathogens may result in direct and indirect crop losses. **Increase in extreme weather events June-July** Hail damage (Paul, 2003).	Better yield potential and oil production, earlier harvesting, fits better in the harvesting conveyer, as a pre-crop for winter cereals rather than summer rapeseed. Preferred crop in soils with high organic matter content but unsuitable in light, drought-susceptible soils (Polna, 1964).
Winter turnip rape	**Higher temperatures and precipitation level November – March** Highly fluctuating winter conditions with warm-cold spells and liquid precipitations are likely to cause overwintering damage incl. overwintering diseases. **Elevated temperatures and water deficit** (drought) following a long cool season in spring may cause physiological infertility in flowering phase and consequent yield loss (Paul, 2003).	More winter tolerant crop with fewer pests and diseases, earlier flowering and maturity, in comparison with the rapeseed. Good alternative for crop rotation

	Excess water (waterlogging) and **increase in extreme weather events** (hail damage) may destroy plant stands (Paul, 2003).	
Summer rapeseed	**Excess water – autumn rains Aug - Sept** harvesting may be delayed. **Increased abundance of pests and diseases** - higher pest pressure, introduction of new emerging pests and pathogens may result in direct and indirect crop losses. **Increase in extreme weather events June-Sept** Hail damage (Paul, 2003).	Yield max. 4,2 t/ha. No critical overwintering period. Preferred crop in soils with high organic matter content but unsuitable in light, drought-susceptible soils (Polna, 1964).
Summer wheat	**Water deficit** - lack of precipitation after early onset of spring (snow melting) in germination and tillering phase (spring drought) may result in a significant yield loss. **Higher temperatures and water deficit** (late spring heat waves) in tillering phase would promote the faster completion of the development phase so that fewer tillers can develop and the full yield potential cannot be reached. **Increased abundance of pests and diseases** - higher pest pressure, introduction of new emerging pests and pathogens may result in direct and indirect crop losses.	Higher quality and price level in comparison to summer barley. Earliest germination of the summer cereals, with the seedlings resistant to late frosts (-7…-9 °C) (Bessovtseva, and Pihlaste, 1962), thus the earlier onset of the vegetation period may shift the sowing dates earlier. Increasing potential to grow varieties of higher yield potential.
Summer barley	**Water deficit** (lack of precipitation) in germination phase End of Apr - May (spring drought) may result in a significant yield loss. **Higher temperatures and water deficit** (late spring heat waves) in tillering stage (May II-III) would promote the faster completion of the development phase so that fewer tillers can develop and the full yield potential cannot be reached. **Increased abundance of pests and diseases** - higher pest pressure, introduction of new emerging pests and pathogens may result in direct and indirect crop losses. **Increase in extreme weather events** (severe late frosts (-7 °C)) may damage the developing seedlings in spring as they are less resistant than in wheat or oats (Bessovtseva and Pihlaste, 1962).	Less prone to diseases, smaller requirement for inputs (IPM, fertilizers) in comparison to summer wheat. Yield max. 8,6t/ha. Least sensitive to cool onset of the vegetation period in comparison to other summer cereal crops, with the seedlings less resistant to late frosts than summer wheat (-4…-6 °C) (Bessovtseva, and Pihlaste, 1962). Earliest crop, less sensitive to drought and highest tillering capacity of the summer cereals, with crop potential exceeding the yield of wheat in a dry summer (Bessovtseva and Pihlaste, 1962).
Oats	**Water deficit** (lack of precipitation) in tillering phase (spring drought) may result in a significant yield loss (Kaasik et al, 2015), especially in delayed sowing dates (Bessovtseva and Pihlaste, 1962.) **Higher temperatures** and **water deficit** (drought damage) in germination phase as well as 10-15 days prior to heading may cause heat damage (Bessovtseva and Pihlaste, 1962.) **Water deficit** (delayed germination) or **excess water** during pre-harvest period may cause severe quality and/or yield loss. **Increase in extreme weather events -** early frost damage occurs at -2…-4 °C in milk ripe phase after a cool moist season which delay harvesting (Bessovtseca and Pihlaste, 1962). The growth period of oats is naturally long (long day photoperiodic crop type),	Primary cash crop in organic cereal production. Less prone to diseases, in comparison to summer barley. Suitable almost in any (but not waterlogged nor dried) soils and humid vegetation period with moderate temperatures (Bessovtseva and Pihlaste, 1962.) Seedlings may withstand minor late frosts (-3…-4 °C) (Bessovtseva and Pihlaste, 1962).

	extending even further in cool moist season.	
Field peas	**Excess water -** Heavy rains (at heading or grain-filling) may cause lodging, direct yield loss and may interrupt with mechanical harvesting due to waterlogging throughout the pre-harvest period. **Increased abundance of pests and diseases** - higher pest pressure, introduction of new emerging pests and pathogens may result in direct and indirect crop losses. **Water deficit:** field peas of grain type (determinant) are sensitive to drought during the flowering period, which may cause significant yield losses (Older, 1999).	More resistant to diseases than the faba bean. Good pre-crop for winter-cereals (except for winter rape). Yield max. 6,8 t/ha.
Faba bean	More susceptible to diseases, comparing to field peas. **Increased abundance of pests and diseases** - higher pest pressure, introduction of new emerging pests and pathogens may result in direct and indirect crop losses. **Increase in extreme weather events June-July** Hail damage (Paul, 2003).	Not susceptible to pre-harvest lodging, perspective crop for widening the harvest window.
Soya	**Increase in extreme weather events June-July** Hail damage (Paul, 2003). **Increased abundance of pests and diseases** - higher pest pressure, introduction of new emerging pests and pathogens may result in direct and indirect crop losses.	A perspective legume crop for warm soils; lower developmental threshold 10–11 °C . Longer vegetation period would promote the development of the crop. Currently, a farm produces 9 ha soy for seed. Good marketing potential; good crop for vegetarian diet.
Buck-wheat	**Increase in extreme weather events: s**eedlings and young plants are frost-tender; the damage occurs at -2…-5 °C (Eichenbaum, 1964). **Elevated temperatures** (30…35 °C) and **water deficit** during the flowering phase cause significant yield loss (Eichenbaum, 1964). **Increase in extreme weather events June-July** Hail damage (Paul, 2003).	Indeterminant, high nutritional value for healthy (e.g. gluten free) diet. High developmental threshold 7…8 °C is why the crop is favoured by warmer weather (Eichenbaum, 1964). Preferred crop in warm, humid summer (Eichenbaum, 1964). Short growth period, good crop for crop rotation, to widen the harvest window.
Potato	**Increased abundance of pests and diseases** - Appearance of the second mating type of the causative agent of late blight (*P. infestans)* has enabled the sexual reproduction of the pathogen, which produces the persistent oospores remaining viable in the field soil. Hence the crop gets infected as early as in June, and the full crop potential is not achieved without continuous application of fungicides. **Excess water / water deficit** in summer are primary factors influencing the yield whilst other environmental factors and agrotechnology could cause only minor alterations on the main effect (Saue, 2011.) **Increase in extreme weather events:** late and early frost damage (-0…-2 °C) (Bessovtseva, Pihlaste, 1962). Regional differences may be expressed in the scope of critical	Warmer vegetation period promotes the development of late varieties, whereas the early varieties don't get the chance to develop the full yield potential (Saue, 2011).

	climatic factors.	
Strawberry	**Higher temperatures and precipitation level November – March** Highly fluctuating winter conditions with warm-cold spells and liquid precipitations and lack of snow cover (**higher temperatures)** during freezing (< -20 °C) may become critical for overwintering . **Late frost** damage in spring in flowering phase may cause severe yield loss. **Increased abundance of pests and diseases** - higher pest pressure, introduction of new emerging pests and pathogens may result in direct and indirect crop losses. **Higher temperatures** and fluctuating precipitation (**excess water/ water deficit**) level may result in loss of yield and quality.	Different cultivars adapted to warmer climate –**higher temperatures and longer vegetation period**. Frost damage may affect the overwintering success of the pests.
Vegetables	**Increased abundance of pests and diseases** - higher pest pressure, introduction of new emerging pests and pathogens may result in direct and indirect crop losses. **Elevated temperatures** and **water deficit** (drought) in germination or ripening phase may cause direct yield loss or quality loss. Sensitive to hail damage and therefore loss of quality (**increase in extreme weather events**). **water deficit** would increase direct production costs due to irrigation need .	Longer vegetation period would promote the development of the crop –**higher temperatures and longer vegetation period**. Longer frost-free periods and higher temperatures will enable to grow crops adapted to warmer climate (ie. tomato, pepper in open field).

Near future (about 2030):

For the immediate future, the models have not yet predicted significant changes in climatic conditions. Thus, we may predict that the weather phenomena will continue to follow current trends and no substantial change of vulnerabilities can be foreseen. Nevertheless, risk of extreme weather events may randomly become critical, at some locations. Noticeable increase in crop yields may be a positive consequence of the climate change.

5.2.4.2 PERMANENT CROPS

The climate risks which are the most prevalent in permanent crops are linked to an increase in extreme weather events, e.g. through, hail damage, and heat stress. These weather events lead to damage of the fruits and to a decline in fruit quality. Climate opportunities are the cultivation of cultivars adapted to warmer climates.

Table 30: Agro-climate grid for permanent crops in Estonia

Permanent crops	Climate risks	Climate opportunities
Vineyards	**Higher temperatures and precipitation level November – March** Highly fluctuating winter conditions with warm-cold spells and liquid precipitations are likely to break dormancy, after which the plant gets susceptible to frost damage. **Higher temperatures -** Earlier onset of the spring brings the shoots to develop, leads to susceptibility to late frost damage. **Increase in extreme weather events -** hail damage may cause loss of quality, and the need to use protective winter or hail covers would increase direct production costs. **Increased abundance of pests and diseases** - higher pest pressure, introduction of new emerging pests and pathogens may result in direct and indirect crop losses. **Excess water** and infections (**increased abundance of pests and diseases**) may lead to bursting of fruits and consequent loss of quality.	**Higher temperatures** promote increasing sugar content and decreasing acid content to recommended level and consequent increase in quality. High potential crop due to **increasing temperatures** turning the current wine production areas too hot and causing excess sugar levels, whereas the production of dry wines shifts further on to North. Different grape cultivars adapted (e.g. Riesling, Pinot Noir) to warmer climate –**higher temperatures and longer vegetation period**. Growing table grapes outdoors (until now only in polytunnels) due to **higher temperatures**.
Apples	**Increased abundance of pests and diseases** - higher pest pressure, introduction of new emerging pests and pathogens may result in direct and indirect crop losses. **Increase in extreme weather events -** to hail and thunderstorm damage.	Cultivation of apple cultivars adapted to warmer climate (e.g. Royal Gala, Red Prince) due to **higher temperatures**.
Blueberry	**Higher temperatures and precipitation level November – March** Highly fluctuating winter conditions with warm-cold spells and liquid precipitations are likely to break dormancy, after which the plant gets susceptible to frost damage. **Increase in extreme weather events -** the need to use protective winter covers would increase direct production costs. **Increased abundance of pests and diseases** - higher pest pressure, introduction of new emerging pests and pathogens may result in direct and indirect crop losses.	Longer vegetation period increases the opportunity to select late varieties to increase the overwintering success. Perspective crop as a “superfruit” with increasing demand and high marketability.

Near future (about 2030):

Hail and thunderstorms have the highest damage potential for permanent crops. Also late frosts may cause significant damage.

For viticulture we see more climate opportunities then risks in near future. Now, the sugar content is too low and acid content too high for wine making, due to higher temperatures it can reach recommended levels. At the same time occurrence of pests and diseases will probably increase and therefore pesticide use a necessity.

5.2.4.3 LIVESTOCK

Direct impacts

The direct impact of climate change on landless and intensive livestock husbandry systems such as poultry and pig production will be less affected compared with grazing and mixed-livestock systems, because of the possibility to control indoor microclimate. However, increased investments will be needed to improve cooling systems in the stables. Over time, heat stress can increase vulnerability to disease and reduce feed intake, fertility, milk production and fattening performance (Özkan et al., 2016). Warmer winters and the earlier onset of spring could probably allow some parasites and pathogens to survive better.

Table 31: Agro-climate grid for animals (direct impacts) in Estonia

Animals	Climate risks	Climate opportunities
Dairy cattle, Beef cattle, Sheep, Goats, Pig, Poultry	**Increase of GHG, ammonia and odours emissions** Drought (**water deficit)** - reduced availability of drinking water and roughage. More heat stress (**higher temperatures)** on animals during the summer period (Kaasik et al., 2015), cooling systems are needed which increases the direct production costs. Reduced feed intake, reproduction (both male and female), growth rate, welfare, milk performance, and changes milk composition due to heat stress (**higher temperatures)** (less protein and fat, higher SCC).	**Higher average temperature**s promote construction of cheaper (uninsulated) livestock buildings and reduces heating cost in winter. Longer vegetation period will increase the use of fertilizers, incl. manure, decreasing the need for manure storage facilities. Longer vegetation period will increase the amount of roughages - more cuts, but 2nd etc. cuts value is lower in comparison to 1st cut value.
Aquaculture	Temperature stress (**higher temperatures),** Drought periods (**water deficit)** may lead to exhaustion of water resources.	Higher winter temperatures would benefit the overwintering success and performance of fish Higher perspective to produce fish adapted to moderate temperatures e.g. the common carp.

Indirect impacts

Table 32: Agro-climate grid for animals (indirect impacts) in Estonia

Fodder crops	Climate risks	Climate opportunities
Permanent and temporary grasslands	Spring drought (**water deficit)** can suppress the development of grasses.	Longer vegetation period will increase the grazing period and amount of roughages.
Maize silage	Sensitive to low temperatures early in the season, when long cool periods may detain the growth (**increase in extreme weather events)**; young plants may tolerate minor frosts (-3 °C) (Tääger, 1964). Sensitive to waterlogging (**excess water)** and acidic soil reaction (Tääger, 1964) as well as to early frost damage **(increase in extreme weather events**) – decreasing the harvest window and quality.	High energy silage crop, High biomass production. Lower developmental threshold 10 – 13 °C. Drought resistant in the beginning of the vegetation period (Tääger, 1964). Higher average temperature and abundant precipitation in the second half of the vegetation period promotes the cultivation of maize for silage.
Cereals and protein crops	See Table 29	See Table 29

Higher temperatures, increased precipitation and reduced snow cover promote traditional practices of animal husbandry. Grasslands could green up earlier in spring and senescence later in the autumn, but would suffer more and longer droughts in between. Higher incidence of drought can complicate the production of livestock in summer period due to the shortage of feed. Climate change could make grasslands more productive in Northern climate region. Recent study in North America estimated an increase in growing season length of up to 5 weeks and 18 % increase of annual grassland productivity by 2100 (Hufkens et al., 2016). Höglind et al. (2013) assessed the impact of climate change on two major grass species, timothy (winter-hardy) and ryegrass (less winter-hardy) at 14 locations in Northern Europe (Iceland, Scandinavia, Baltic countries) in a near-future scenario (2040–2065) compared with the baseline period 1960–1990. They concluded that grass yield will increase less in the eastern than in the western part of northern Europe because the dryer conditions in the east. The yield increase (average 11 - 14 %) was mainly due to the **increased number of cuts** per year rather than increased yield in individual cuts. In Northern Europe the risk of winter-related damage to timothy grass is likely to be reduced but there will be slight increase in the risk of ice encasement and spring frost at some coastal locations. The same study prognosed an increase in the **risk of winter frost damage** (due to large reduction in the number of days with insulating snow cover, exposing the plants to frosts) at Jokioinen (Finland) and Tartu (Estonia), in contrast to the other study locations.
Contamination by Fusarium mycotoxins, especially deoxynivalenol (DON) and zearalenone (ZEN) represent a problem In Northern Europe, but is very much dependent on regional climatic conditions. Excessive moisture, temperature extremes, humidity, drought conditions, insect damage, crop systems and some agronomic practices can cause stress and will determine the degree of mycotoxin contamination. Fusarium spp. producing DON and ZEN are usually related with cool and wet growing seasons. In general, if the temperature increases in cool or temperate climates, the relevant countries may become more liable to aflatoxins, as well (Battilani et al., 2016).
Climate change may cause more storms resulting in power cuts, whereas failures of electric automation equipment may potentially be of fatal consequences (Kaasik et al., 2015). Increasingly more infections and vector species associated with warmer climates have been found in areas where they previously did not exist.

5.2.5 Estonian bibliography

Aruksaar, H., Liidemaa, H., Martin, I. Mürk, H. Nei, I., Põiklik, K. 1964. Üld- ja agrometeoroloogia. Koost. K. Põiklik, Eesti Raamat. 768 pp.

Battilani, P., Toscano, P., Van der Fels-Klerx, H.J., Moretti, A., Camardo Leggieri, M., Brera, C., Rortais, A., Goumperis, T., Robinson, T. (2016). Aflatoxin B1 contamination in maize in Europe increases due to climate change. Sci. Rep. 6 doi: 10.1038/srep24328.

Bessovtseva, A.; Pihlaste, L. 1962. Põllumajanduskultuuride kasvutingimuste agroklimaatiline iseloomustus (Agro-climatical characterization of the growing conditions of the agricultural crops). in: Eesti NSV agroklimaatiline teatmik, ed.: Ruubel, H. Eesti Riiklik Kirjastus, Tallinn, 196 pp.

Eichenbaum, Ed. 1964. Tatar (Buckwheat). In: Taimekasvatus, ed. Tääger, A. Eesti Raamat, Tallinn, p. 181-193.

Hufkens, K., Keenan, T., Flanagan, L., Scott, R.L., Bernacchi, C.J., Joo, E., Brunsell, N., Verfaillie, J., Richardson, A. 2016. Productivity of North American grasslands is increased under future climate scenarios despite rising aridity. Nature Climate Change. doi: 10.1038/nclimate2942.

Höglind, M., Thorsen, S. M., Semenov, M. A. (2013). Assessing uncertainties in impact of climate change on grass production in Northern Europe using ensembles of global climate models. Agricultural and Forest Meteorology, 170, 103-113.

Kaasik, A., Kauer, K., Kruus, E., Lauringson, E., Leming, R., Mänd, M. 2015. Põllumajandus. in: Suškevič, et al. (ed.) BioClim: Kliimamuutuste mõjuanalüüs, kohanemisstrateegia ja rakenduskava looduskeskkonna ja biomajanduse teemavaldkondades. III vahearuanne, 30.06.2015. http://www.klab.ee/kohanemine/wp-content/uploads/sites/4/2016/04/2016-04-07-BIOCLIM_Lopparuanne.pdf

Kaasik, A., Maasikmets A. 2013. Concentrations of airborne particulate matter, ammonia and carbon dioxide in large scale uninsulated loose housing cowsheds in Estonia. Biosystems Engineering, 114, 223–231.

Kallis, A.; Kull, A.; Roose, A.; Järvet, A.; Kriis, E.; Abroi, E.L.; Põdersalu, H.; Laas, I.; Võrno, I.; Jaagus, J.; Kriiska, K.; Eerme, K.; Lember, K.; Rannik, K.; Aidla, K.; Kaar, K.; Kaare, K.; Sakkeus, L.; Kaasik, M.; Mandel, M. ... Suursaar, Ü. (2014). Eesti Kuues Kliimaaruanne. ÜRO kliimamuutuste raamkonventsiooni elluviimise kohta. Tallinn: -.260 pp, http://www.envir.ee/sites/default/files/elfinder/article_files/kliimaaruanne_et.pdf

Keskkonnaministeerium, 2016. Kliimamuutuste mõjuga kohanemise arengukavas aastani 2030. http://www.envir.ee/sites/default/files/kliimamuutustega_kohanemise_arengukava_aastani_2030_0.pdf

Leming, R.; Aart, M.; Kaasik, A.; Karp, K.; Kauer, K.; Keres, I.; Kruus, E.; Lauringson, E.; Mandel, M.; Ots, M.; Põldma, P.; Saue, T.; Uustal, T., 2017. Expert consultations for the LIFE 2015: Sustainable adaptation of typical EU farming systems to climate change. Minutes of the meeting. EMU.

Luhamaa, A., Kallis, A., Mändla, K., Männik, A., Pedusaar, T., Rosin, K. 2014. Eesti tuleviku kliima stsenaariumid aastani 2100. Lepingulise töö aruanne projekti “Eesti riikliku kliimamuutuste mõjuga kohanemise strateegia ja rakenduskava ettepaneku väljatöötamine" lisana. Keskkonnaagentuur. 94 pp.

Luhamaa, A., Kallis, A., Mändla, K., Männik, A., Pedusaar, T., Rosin, K. 2015. Eesti tuleviku kliimastsenaariumid aastani 2100. Lõpparuanne. Keskkonnaagentuur. 35 pp. http://www.klab.ee/kohanemine/wp-content/uploads/sites/4/2016/04/2016-04-07-KAUR_Lopparuanne.pdf

Maanso, A. 2016. Põllumajandus/Agriculture. Eesti Statistika aastaraamat 2016/Statistical Yearbook of Estonia. p283-286.

Older, H. 1999. Teraviljakasvatuse käsiraamat (Handbook of cereal production). EV Põllumajandusministeerium, EMVI. 342 pp.

Paul, V.H. 2003. Raps. Krankheiten, Schädlinge, Schadpflanzen. Verlag Th. Mann, Gelsenkirchen-Buer. 208 pp.

Polna, H. 1964. Suviraps (Summer rapeseed). In: Taimekasvatus, ed. Tääger, A. Eesti Raamat, Tallinn, p. 690-693.

Saue, T. 2015. Projekti "Kliimamuutuste mõju põllukultuuridele" lõpparuanne. ETKI, 8pp.

Tõnisson, H. 1964. Talioder (Winter barley). In: Taimekasvatus, ed. Tääger, A. Eesti Raamat, Tallinn, p. 102.

Tääger, A. 1964. Mais (Maize). In: Taimekasvatus, ed. Tääger, A. Eesti Raamat, Tallinn, p. 194-210.

Viru, B. (2014) Pikaajalised muutused vegetatsiooniperioodi algus- ja lõpukuupäevades ning kestuses Eestis perioodil 1951–2012. Bakalaureusetöö loodusgeograafias. TÜ Loodus- ja tehnoloogiateaduskond, Ökoloogia ja maateaduste instituut, Geograafia osakond. 35 lk.

Özkan, S.; Vitali, A.; Lacetera, N.; Amon, B.; Bannink, A.; Bartley, D. J.; Blanco-Penedo, I.; de Haas, Y.; Dufrasne, I.; Elliott, J.; Eory, V.; Fox, N. J.; Garnsworthy, P. C.; Gengler, N.; Hammami, H.; Kyriazakis, I.; Leclère, D.; Lessire, F.; Macleod, M.; Robinson, T. P.; Ruete, A.; Sandars, D. L.; Shrestha, S.; Stott, A. W.; Twardy, S.; Vanrobays, M.-L.; Vosough Ahmadii, B.; Weindl, I.; Wheelhouse, N.; Williams, A. G.; Wilson, A. J.; Østergaard, S.; Kipling, R. P. (2016): Challenges and priorities for modelling livestock health and pathogens in the context of climate change. Environmental Research, 151, 130-144 p.

List of Estonian experts identified

- Ants-Hannes Viira, Estonian University of Life Sciences
- Indrek Keres, Practicing advisor for the Estonian agricultural and rural advisory service
- Kadri Karp, Estonian University of Life Sciences
- Kalvi Tamm, Estonian Crop Research Institute
- Karin Kauer, Estonian University of Life Sciences
- Martti Mandel, Ministry of Rural Affairs
- Meelis Ots, Estonian University of Life Sciences
- Merry Aart, Practicing advisor for the Estonian agricultural and rural advisory service
- Timo Uustal, The Estonian Environment Agency
- Triin Saue, Estonian Crop Research Institute

Glossary

CMIP3 and CMIP5

Phases three and five of the Coupled Model Intercomparison Project (CMIP3 and CMIP5), coordinating and archiving climate model simulations based on shared model inputs by modeling groups from around the world. The CMIP3 multi-model data set includes projections using SRES scenarios. The CMIP5 data set includes projections using the Representative Concentration Pathways (IPCC, 2014).

Representative Concentration Pathways (RCPs)

Scenarios that include time series of emissions and concentrations of the full suite of greenhouse gases and aerosols and chemically active gases, as well as land use/land cover (Moss et al., 2008). The word representative signifies that each RCP provides only one of many possible scenarios that would lead to the specific radiative forcing characteristics. The term pathway emphasizes that not only the longterm concentration levels are of interest, but also the trajectory taken over time to reach that outcome (Moss et al., 2010).
RCPs usually refer to the portion of the concentration pathway extending up to 2100, for which Integrated Assessment Models produced corresponding emission scenarios. Extended Concentration Pathways (ECPs) describe extensions of the RCPs from 2100 to 2500 that were calculated using simple rules generated by stakeholder consultations, and do not represent fully consistent scenarios.
Four RCPs produced from Integrated Assessment Models were selected from the published literature and are used in the present IPCC Assessment as a basis for the climate predictions and projections in WGI AR5 Chapters 11 to 14:

- RCP2.6 One pathway where radiative forcing peaks at approximately 3 W m^{-2} before 2100 and then declines (the corresponding ECP assuming constant emissions after 2100).
- RCP4.5 and RCP6.0 Two intermediate stabilization pathways in which radiative forcing is stabilized at approximately 4.5 W m^{-2} and 6.0 W m^{-2} after 2100 (the corresponding ECPs assuming constant concentrations after 2150).
- RCP8.5 One high pathway for which radiative forcing reaches greater than 8.5 W m^{-2} by 2100 and continues to rise for some amount of time (the corresponding ECP assuming constant emissions after 2100 and constant concentrations after 2250).

SRES scenarios

SRES scenarios are emission scenarios developed by Nakićenović and Swart (2000) and used, among others, as a basis for some of the climate projections shown in Chapters 9 to 11 of IPCC (2001) and Chapters 10 and 11 of IPCC (2007). The following terms are relevant for a better understanding of the structure and use of the set of SRES scenarios:

- *Scenario family:* Scenarios that have a similar demographic, societal, economic, and technical change storyline. Four scenario families comprise the SRES scenario set: A1, A2, B1, and B2.
- *Illustrative scenario A:* scenario that is illustrative for each of the six scenario groups reflected in the Summary for Policymakers of Nakićenović and Swart (2000). They include four revised marker scenarios for the scenario groups A1B, A2, B1, and B2, and two additional scenarios for the A1FI and A1T groups. All scenario groups are equally sound.
- *Marker scenario A:* scenario that was originally posted in draft form on the SRES web site to represent a given scenario family. The choice of markers was based on which of the initial quantifications best reflected the storyline, and the features of specific models. Markers are no more likely than other scenarios, but are considered by the SRES writing team as illustrative of a particular storyline. They are included in revised form in

Nakićenović and Swart (2000). These scenarios received the closest scrutiny of the entire writing team and via the SRES open process. Scenarios were also selected to illustrate the other two scenario groups.

- *Storyline A:* narrative description of a scenario (or family of scenarios), highlighting the main scenario characteristics, relationships between key driving forces, and the dynamics of their evolution.