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An indicator-based report

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Executive summary

Key messages

- **All of the key findings from the 2012 European Environment Agency (EEA) report on climate change, impacts and vulnerability in Europe are still valid.**
- **Climate change is continuing globally and in Europe**. Land and sea temperatures are increasing; precipitation patterns are changing, generally making wet regions in Europe wetter, particularly in winter, and dry regions drier, particularly in summer; sea ice extent, glacier volume and snow cover are decreasing; sea levels are rising; and climate-related extremes such as heat waves, heavy precipitation and droughts are increasing in frequency and intensity in many regions.
- **New record levels of some climatic variables have been established in recent years**, notably global and European temperature in 2014 and again in 2015, global sea level in 2015 and winter Arctic sea ice extent in 2016. Some climatic changes have accelerated in recent decades, such as global sea level rise and the decline of the polar ice sheets.
- **Global climate change has substantially increased the probability of various recent extreme weather and climate events in Europe**. The reliability of this finding has been strengthened by recent progress in extreme weather attribution techniques.
- **The observed changes in climate are already having wide-ranging impacts on ecosystems, economic sectors and human health and well-being in Europe**. Recent studies show that various observed changes in the environment and society, such as changes in forest species, the establishment of invasive alien species and disease outbreaks, have been caused or enhanced by global climate change.
- **Ecosystems and protected areas are under pressure from climate change and other stressors, such as land use change. The observed impacts of climate change are a threat to biodiversity in Europe, but they also affect forestry, fishery, agriculture and human health**. In response to climate change, many land-based animal and plant species are changing their life cycles and are migrating northwards and to higher altitudes; regional extinctions have been observed; various invasive alien species have established themselves or have expanded their range; and various marine species, including commercially important fish stocks, are migrating northwards.
- **Most impacts of climate change across Europe have been adverse, although some impacts have been beneficial**. The rise in sea level has increased flood risks and contributed to erosion along European coasts. The observed increase in heat waves has had significant effects on human health, in particular in cities. Heat waves are also increasing the risk of electricity blackouts and forest fires. Transport and tourism have also been affected by climate change, with large regional differences. Examples of beneficial impacts of climate change include a decrease in heating demand and some benefits to agriculture in northern Europe.
- **Climate change will continue for many decades to come, having further impacts on ecosystems and society**. Improved climate projections provide further evidence that future climate change will increase climate-related extremes (e.g. heat waves, heavy precipitation, droughts, top wind speeds and storm surges) in many European regions.
- **The magnitude of future climate change and its impacts from the middle of the century onwards depend on the effectiveness of global climate mitigation efforts**. The magnitude of climate change and its impacts can be substantially reduced by an ambitious global mitigation policy compatible with the mitigation goal of the 2015 Paris Agreement under the United Nations Framework Convention on Climate Change (UNFCCC) of keeping the increase in global average temperature to well below 2 °C above pre-industrial levels.

Key messages (cont.)

- **Future climate change will interact with other socio-economic developments**, including the ageing of the population and increasing urbanisation across Europe, projected decreases in population size in eastern Europe, and a narrowing economic gap between eastern and western parts of Europe. **The water sector, agriculture, forestry and biodiversity show strong interdependencies**, and are also related to changing land-use patterns and population change.

- **Climate change is affecting all regions in Europe, but the impacts are not uniform**. South-eastern and southern Europe are projected to be hotspot regions, having the highest numbers of severely affected sectors and domains. Coastal areas and floodplains in the western parts of Europe are also multi-sectoral hotspots. The Alps and the Iberian Peninsula are additional hotspots for ecosystems and their services. Ecosystems and human activities in the Arctic will be strongly affected owing to the particularly fast increase in air and sea temperatures and the associated melting of land and sea ice.

- **Economic costs can potentially be high, even for modest levels of climate change**, and these costs rise significantly for scenarios of greater levels of warming. The projected damage costs from climate change are **highest in southern Europe**. However, estimates of the projected economic impacts of climate change in Europe consider only some sectors and show considerable uncertainty.

- **Europe is vulnerable to climate change impacts outside Europe** through six major pathways: the trade of agricultural commodities, the trade of non-agricultural commodities, infrastructure and transport, geopolitics and security risks, human mobility related to migration and finance. The strongest evidence for Europe's vulnerability to cross--border impacts are the economic effects seen as a result of climate-related global price volatilities and disruptions to transportation networks. The Mediterranean area is most vulnerable to shocks in the flow of agricultural commodities, while small, open and highly developed European economies are particularly vulnerable to shocks in the flow of non-agricultural commodities. **European vulnerability to cross-border effects is expected to increase** in the coming decades, but quantitative projections are not available.

- **Climate change adaptation strategies, policies and actions, including the mainstreaming of them into other policies, are progressing at all governance levels** (European Union (EU), transnational, national and local levels). Further actions could include enhancing policy coherence across EU environmental and sectoral policies; effective and efficient action across all levels of governance, through multi-level governance and transnational cooperation platforms; enhancing flexible 'adaptive management' approaches; combining technological solutions, ecosystem-based approaches and 'soft' measures; involving the private sector; and more emphasis on 'transformational' adaptation actions as a complement to 'incremental' adaptation.

- **The knowledge base regarding climate change impacts, vulnerability, risk and adaptation assessments in Europe could be enhanced**, e.g. through improved monitoring and reporting of climate-related extremes and the associated damage, enhanced national and sectoral assessments and their reporting, and further monitoring, reporting and evaluation of adaptation actions at the national level. More knowledge would also be useful on the costs and benefits of adaptation options and on interdependencies, synergies and trade-offs between adaptation policies and other policies and actions. The use of European, transnational and national climate change and adaptation services by stakeholders could be further improved. The European Commission's 'adaptation preparedness scoreboard', which assesses the progress of Member States using process-based indicators (and is due to be published in 2017 as part of its report on the EU Adaptation Strategy), could be complemented by quantitative information. The indicators of the Sendai Framework for Disaster Risk Reduction (which are to be agreed by the end of 2016) for weather- and climate-related hazards are expected to be relevant for climate change adaptation. EU-funded and national research can address adaptation knowledge gaps and stimulate innovation.

ES.1 Introduction

The climate is changing globally and in Europe. The Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2013) concluded that the warming since the mid-20th century has predominantly been due to greenhouse gas emissions from human activities, in particular the combustion of fossil fuels, agriculture and other changes in land use.

There is a need to reduce global greenhouse gas emissions substantially to avoid the most adverse impacts of climate change. However, even with substantial reductions in greenhouse gas emissions, the climate will continue to change, and the impacts will be felt across the world, including in Europe. Climate change is having a variety of impacts on our health, ecosystems and economy, often in interaction with other factors such as land-use changes. These impacts are likely to become more severe in the coming decades. If not addressed, these impacts could prove very costly, in terms of ill health, adverse effects on ecosystems and damaged property and infrastructure, and some impacts may be irreversible. As mitigation cannot prevent all of the impacts of climate change, there is also a need to adapt to our changing climate.

This report presents a largely indicator-based assessment of past and projected climate change, impacts and the associated vulnerabilities of and risks to ecosystems, human health and society in Europe, based on a wide range of observations and model simulations. It identifies regions that are experiencing particularly severe climate change impacts. The report also shows how Europe is vulnerable to climate change impacts outside Europe. The principal sources of uncertainty for the indicators and modelling results are discussed and, where appropriate, reflected in the assessments and key messages of all indicators.

The report summarises key adaptation policy developments at European, transnational and national levels and highlights the need for further adaptation actions. Furthermore, the report notes how monitoring, information sharing and research can improve the knowledge base for adaptation.

This report is part of a series of European Environment Agency (EEA) reports, prepared in collaboration with other organisations, and to date has been published at four-year intervals. Publishing this report at this frequency serves the policy need for a regular comprehensive European-wide assessment and allows new scientific knowledge accumulated over that period to be included. In particular, the report aims to support the implementation and review process of the 2013 European Union (EU) Adaptation Strategy (EC, 2013) foreseen for 2018.

This report compiles information from a wide variety of data and information sources. It builds on, among others, the IPCC Fifth Assessment Report, but a substantial amount of information that became available afterwards has also been included. Major new information that has become available since the 2012 EEA report on climate change, impacts and vulnerability in Europe (EEA, 2012) is highlighted in this summary.

The indicators included in this report are based on many different information sources. As a result, they cover different past and future time periods, and information is presented at different levels of regional aggregation.

ES.2 Policy context

Adaptation policies aimed at limiting the adverse impacts of climate change interact with many other policies, such as broader environmental, climate change mitigation and disaster risk reduction policies. This section gives an overview of relevant policies at different governance levels.

Global policies

In December 2015, the member countries of the United Nations Framework Convention on Climate Change (UNFCCC) adopted the Paris Agreement, which includes the long-term goals of keeping the increase in global average temperature to well below 2 °C above pre-industrial levels and of pursuing efforts to limit the increase to 1.5 °C above pre-industrial levels, since this would significantly reduce risks and the impacts of climate change (UNFCCC, 2015). Countries also agreed on the need for global emissions to peak as soon as possible, recognising that this will take longer for developing countries, and the need to undertake rapid reductions thereafter in accordance with the best available science. However, the combined emissions reduction foreseen under currently available national climate action plans is not enough to keep global warming below 2 °C; in fact the current plans may lead to an increase of 3 °C or more (UNEP, 2015). Subsequent meetings of the UNFCCC aim to address this gap.

Within the Paris Agreement, countries also established an adaptation goal of 'enhancing adaptive capacity, strengthening resilience and reducing vulnerability to climate change', and an aim to strengthen societies' ability to deal with the impacts of climate change, to engage in national adaptation planning processes and to provide continued and enhanced international support for adaptation to developing countries.

Climate change action has increasingly become an integrated part of economic analyses and a prominent element of risk assessments by public and private bodies. For example, the most recent Global Risks Report of the World Economic Forum (WEF, 2016) indicates that the most impactful risk (i.e. the risk with the greatest potential damage) for the years to come is a failure in climate change mitigation and adaptation.

In 2015, the Sendai Framework for Disaster Risk Reduction was adopted (UN, 2015a). It is a voluntary agreement that includes four priorities for action: understanding disaster risk, strengthening disaster risk governance to manage disaster risk, investing in disaster risk reduction for resilience and enhancing disaster preparedness. The framework acknowledges climate change as one of the drivers of disaster risk. An important element is alignment with the other post-2015 international agendas on climate change (UNFCCC, 2015) and on sustainable development (UN, 2015b). The 2030 agenda for sustainable development has 17 overarching sustainable development goals and within each is a range of targets, and the challenges to address the effects of climate change are explicitly acknowledged.

EU 7th Environment Action Programme

In the 7th Environment Action Programme (EAP), 'Living well, within the limits of our planet' (EU, 2013b), the EU formulates a vision of the future up to 2050: a low-carbon society, a green, circular economy and resilient ecosystems as the basis for citizens' well-being. Achieving this 2050 vision requires a focus on actions in three key areas:

- protecting the natural capital that supports economic prosperity and human well-being;
- stimulating resource-efficient, low-carbon economic and social development; and
- safeguarding people from environmental health risks.

The 7th EAP mentions explicitly that action to mitigate and adapt to climate change will increase the resilience of the EU's economy and society, while stimulating innovation and protecting the EU's natural resources.

According to the EEA report *The European environment — state and outlook 2015* (SOER 2015), the implementation of environment and climate policies during the last 40 years has delivered substantial benefits for the functioning of Europe's ecosystems and for the health and living standards of its citizens (EEA, 2015b). Reduced pollution, nature protection and better waste management have all contributed to this. However, the SOER 2015 also highlights that substantial challenges remain in each of the above-mentioned three areas.

Europe's natural capital is not yet being protected, conserved or enhanced sufficiently. The loss of soil functions, land degradation and climate change remain major concerns. Europe is not on track to meet its overall target of halting biodiversity loss by 2020. Looking ahead, climate change impacts are projected to intensify, and the underlying drivers of biodiversity loss are expected to persist.

Regarding resource efficiency and the low-carbon society, EU greenhouse gas emissions have decreased since 1990, despite an increase in economic output. Other environmental pressures have also been decoupled in absolute terms from economic growth. Fossil fuel use has declined, as have emissions of some pollutants from transport and industry. However, the greenhouse gas emissions reductions projected under current policies are insufficient to bring the EU onto a pathway in line with its 2050 target.

Environment and climate change issues are characterised by many systemic factors, including feedbacks, interdependencies and lock-ins in environmental and socio-economic systems; unsustainable systems of production and consumption; and increasingly globalised environmental drivers, trends and impacts. Relevant global megatrends include diverging global population trends; a change towards a more urban world; changing disease burdens and risks of pandemics; accelerating technological change; decreasing economic growth; an increasingly multi-polar world; intensified global competition for resources; increasing environmental pollution; diversifying approaches to governance; and increasingly severe consequences of climate change (SOER 2015: EEA, 2015c).

Transforming key systems such as the transport, energy, housing and food systems will be needed to achieve the 7th EAP vision for 2050.

Climate change impacts may hamper the achievement of the 2050 vision for Europe set out in the 7th EAP and, on a global level, the realisation of the sustainable development goals. Therefore, climate change and its impacts should be assessed in conjunction with the above-mentioned factors.

EU climate policy

EU climate change mitigation policy aims to put the EU on track towards a low-carbon economy and to reduce EU greenhouse gas emissions by 80 to 95 % by 2050. The EU is on track towards its 2020 climate targets (EEA, 2015d), but to achieve the longer term goals of the EU for 2030 and 2050 new policies and a more fundamental change are needed in the way the EU produces and uses energy, goods and services.

The 7th EAP calls for decisive progress to be made in adapting to climate change to make Europe more climate-resilient. In 2013, the European Commission adopted the communication 'An EU Strategy on adaptation to climate change' (EC, 2013), which encourages all Member States to adopt comprehensive adaptation strategies; promotes action in cities (through the Covenant of Mayors for Climate and Energy); aims to mainstream adaptation into relevant EU policies and programmes; provides funding for adaptation actions; and enhances research and information sharing (e.g. through the European climate adaptation platform Climate-ADAPT). In 2018, the Commission will present the evaluation of the EU Strategy and will propose a review, if needed. The report will assess the progress made by Member States, including an adaptation preparedness scoreboard, the progress in mainstreaming at the EU level, and new knowledge and policy demands.

The European Multiannual Financial Framework (2014–2020) includes the objective that a minimum of 20 % of the EU budget contributes to climate-related expenditure (including adaptation). Initial analysis shows that this objective will be achieved, but its effectiveness in terms of enhanced resilience and reduced greenhouse gas emissions is yet to be evaluated.

Mainstreaming requires that climate change adaptation is taken into account in implementing EU policies and legislation. Mainstreaming has been increasingly covered in guidance documents and legal texts since 2013. Examples include the EU's Civil Protection legislation (EU, 2013a), which aims to develop a more resilient European society. Since 2015, Member States have had to report on their risk assessments and risk management capabilities, including climate- and weather-related risks, to the European Commission every three years. An analysis of this information by the Commission is expected by the end of 2016. Guidance under the Water Framework Directive required Member States to present river basin management plans by December 2015, and guidance under the Floods Directive required Member States to establish flood risk management plans and to report these by March 2016. The extent to which climate change adaptation was taken into account in these plans has not yet been assessed. Other key EU policies in which adaptation mainstreaming has taken place, to varying degrees, include the EU Biodiversity Strategy, the Marine Strategy Framework Directive, the Habitats Directive, the Birds Directive, the nature protection network Natura2000, the invasive species regulation and regulations addressing environmental sectors such as agriculture and forestry.

A recent review of the EU biodiversity policy in the context of climate change has identified a number of policy gaps: conservation targets need to better match conservation needs; targets need to be set in a spatially coherent manner across national scales; and current monitoring appears insufficient to address these gaps.

National and transnational adaptation policies in Europe

There has been a steady increase over the last five years in national adaptation strategies and plans. By September 2016, 23 EEA member countries (of which 20 are EU Member States) had adopted a national adaptation strategy and 12 (of which nine are Member States) had developed a national adaptation plan. Most progress regarding action plans has been reported for freshwater management, flood risk management, agriculture and forestry, with a focus on mainstreaming adaptation in these national sectoral policy areas. Several countries have also developed national health strategies and action plans. Only a few EEA member countries have started to monitor and report on their progress in adaptation strategies, policies and actions at the national level, and even fewer have started an evaluation of their effectiveness (EEA, 2015a).

Transnational cooperation (e.g. on strategies and on knowledge sharing) in adaptation to climate change has increased, with the importance of adaptation as a cross-cutting policy area being recognised. Adaptation actions take place, for example, within the EU strategies for the Baltic Sea region and the Alpine region, the Danube and Rhine Commissions, the Carpathian and Alpine conventions, the Working Community of the Pyrenees and the Mediterranean Action Plan/Barcelona Convention. Transnational adaptation action is often linked to the sharing of natural resources, such as transboundary water catchments or terrestrial ecosystems.

ES.3 Climate change and its impacts

This section gives an overview of the observed and projected changes in the climate system and in climate-sensitive environmental systems and social domains. The degree of certainty related to specific observations and projections and the importance of non-climatic factors differ substantially across domains and indicators. More detailed quantitative information, including a discussion of relevant uncertainties, is available in the main part of this report.

Climate system

The average concentration of CO_2 in the atmosphere in 2016 reached 400 parts per million (ppm), which is about 40 % higher than the pre-industrial level.

The global average annual near-surface temperature in the decade 2006–2015 was 0.83 to 0.89 °C higher than the pre-industrial average (mid- to the end of the 19th century). Globally, 2015 was the warmest year on record, namely about 1 °C warmer than the pre-industrial temperature. The IPCC Fifth Assessment Report concluded that 'It is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century' (IPCC, 2013).

For most emissions scenarios, global average temperature is projected to exceed 2 °C above pre-industrial levels (the upper limit according to the Paris Agreement under the UNFCCC) by 2050. Even if anthropogenic greenhouse gas emissions were to fall to zero in the very near future, the climate would continue to change for many decades, and sea level would continue to rise for many centuries.

European land temperatures in the decade 2006–2015 were around 1.5 °C warmer than the pre-industrial level, and they are projected to continue increasing by more than the global average temperature increase. Europe has experienced several extreme summer heat waves since 2003, which have led to high mortality and economic impacts. Heat waves of a similar or larger magnitude are projected to occur as often as every two years in the second half of the 21st century under a high emissions scenario. The impacts will be particularly strong in southern Europe.

Precipitation has increased in most of northern Europe, in particular in winter, and has decreased in most of southern Europe, in particular in summer. The projected changes in precipitation show the same pattern of regional and seasonal changes. Heavy precipitation events have increased in several regions in Europe over recent decades, in particular in northern and north-eastern Europe. Heavy precipitation events are projected to become more frequent in most parts of Europe, in particular in winter.

Recent progress in the attribution of extreme weather to specific causes has facilitated many studies, which showed that the probability of occurrence of various recent heat waves and other damaging extreme weather and climate events in Europe has substantially increased as a consequence of anthropogenic climate change.

Observations of wind storm location, frequency and intensity show considerable variability. Most studies agree that the risk of severe winter storms, and possibly of severe autumn storms, will increase in the future for the North Atlantic and northern, north-western and central Europe.

The number of hail events is highest in mountainous areas and the pre-Alpine regions. Despite improvements in data availability, trends and projections of hail events are still uncertain.

Observations show a shrinking and thinning of Arctic sea ice, a decrease of snow cover, a shrinking of glaciers and increased melting of the large polar ice sheets in Greenland and Antarctica. It is estimated that the melting of the polar ice sheets will contribute up to 50 cm to global sea level rise during the 21st century.

The nine lowest Arctic sea ice minima since records began in 1979 have been the September ice cover in each of the last nine years (2007–2015), and the annual maximum ice cover in March 2015 and March 2016 were the lowest on record. The ice is also getting thinner. For high emissions scenarios, a nearly ice-free Arctic Ocean in September is likely before the middle of the 21st century, but there will still be substantial ice in winter.

The vast majority of glaciers in the European glacial regions are in retreat. Glaciers in the European Alps have lost approximately half of their volume since 1900, with clear acceleration since the 1980s. Glacier retreat affects freshwater supply and run-off regimes, river navigation, irrigation and power generation and may lead to natural hazards and damage to infrastructure.

Snow cover extent in the northern hemisphere has declined significantly since the 1920s, with most of the reductions occurring since 1980.

Further reductions of the cryosphere are projected for the future. The melting of ice and snow and the thawing of permafrost soil cause positive feedbacks that can accelerate climate change further.

Ecosystems and their services

Ecosystems globally and in Europe are under five major pressures (Millennium Ecosystem Assessment, 2005; EEA, 2016a): habitat change (e.g. land and sea take, urban sprawl, fragmentation and land abandonment);

dispersal of invasive alien species; exploitation and management (e.g. land-use change and intensification, unsustainable agriculture and forestry, natural resource consumption); pollution and nutrient enrichment (e.g. atmospheric deposition, fertiliser and pesticide use, irrigation and acidification) and climate change.

Climate change significantly affects ecosystems, their biodiversity and consequently their capacity to provide services for human well-being; it may already have triggered shifts in ecological regimes from one state to another. Climate change also increasingly exacerbates the impact of other human stressors, especially in natural and semi-natural ecosystems.

The knowledge about the combined effects of climate change and other pressures on ecosystems and their capacity to provide services is improving. The relative importance of climate change as a major driver of biodiversity and ecosystem change is projected to increase further in the future, depending on the environmental domain (terrestrial, freshwater or marine) and geographical region.

Oceans, the marine environment and coastal zones

Key observed changes in the ocean are acidification, increased ocean heat content and increased sea surface temperature, and sea level rise. Changes in temperature cause significant shifts in the distribution of marine species towards the poles, but also in depth distribution. For example, a major northwards expansion of warmer water plankton in the North-east Atlantic and a northwards retreat of colder water plankton have been observed, which seems to have accelerated since 2000. Sub-tropical species are occurring with increasing frequency in Europe's seas, and sub-Arctic species are moving northwards. Wild fish stocks are changing their distribution, which can have impacts on local communities that depend on those fish stocks.

Oxygen-depleted zones in the Baltic Sea and in other European seas have substantially increased. The primary cause of oxygen depletion is nutrient input from agricultural fertilisers, but the effects are exacerbated by climate change.

Further changes in the distribution of marine species, including fish stocks, are expected with the further climate change projected. These impacts, in combination with other anthropogenic stressors, in particular overfishing, are projected to cause widespread changes to marine ecosystems and their services.

Mean and extreme sea level have increased globally and along most coasts in Europe. Evidence for an acceleration in the rate of global mean sea level rise during recent decades has increased. The IPCC Fifth Assessment Report has projected that global mean sea level in the 21st century will rise by 26–81 cm, depending on the emissions scenario, and assuming that the Antarctic ice sheet remains stable. Several recent model-based studies and expert assessments have suggested an upper bound (with a probability of 5 % of being exceeded) for global mean sea level rise in the 21st century in the range of 1.5–2.0 m. Sea level will continue to rise for many centuries, even if greenhouse gas emissions and temperature are stabilised.

The projected increases in extreme high coastal water levels are primarily the result of increases in local relative mean sea level, but increases in storm activity can also play a substantial role, in particular along the northern European coastline.

The projected sea level rise, possible changes in the frequency and intensity of storm surges, and the resulting coastal erosion are expected to cause significant ecological damage, economic loss and other societal problems for low-lying coastal areas across Europe unless additional adaptation measures are implemented.

Freshwater systems

River flows have generally increased in winter and decreased in summer, but with substantial regional and seasonal variation. Climate change is an important factor in this, but other factors, such as water abstractions, man-made reservoirs and land-use changes, also have a strong influence. Summer flows are projected to decrease in most of Europe. Where precipitation changes from snow to rain, spring and summer peak river flow will shift to earlier in the season.

The detection of a clear trend in the number and intensity of floods in Europe is impeded by the lack of a consistent dataset for Europe. Reporting under the EU Floods Directive has so far improved this situation to only a limited extent. The reported number of very severe flood events has increased over recent decades, but with large interannual variability. It is not currently possible to quantify the contribution from observed increases in heavy precipitation in parts of Europe compared with the contribution from land-use changes and better reporting.

Without further action, climate change is projected to increase the magnitude and frequency of flood events in large parts of Europe. Pluvial floods and flash floods, which are triggered by intense local precipitation events, are likely to become more frequent throughout Europe. In regions with a projected reduced snow accumulation during winter, the risk of spring flooding could decrease.

The severity and frequency of droughts appear to have increased in parts of Europe, in particular in southern Europe and south-eastern Europe. Droughts are projected to increase in frequency, duration and severity in most of Europe. The strongest increase is projected for southern Europe, where competition between different water users, such as agriculture, industry, tourism and households, is likely to increase.

Climate change has increased the water temperature of rivers and lakes and has shortened seasonal ice cover. These trends are projected to continue.

Changes in river flows and increases in water temperature have important impacts on freshwater ecosystems, such as changes in phenology and in species distribution, the facilitation of species invasions and the deterioration of water quality, for example through enhanced algal blooms. They can also have an impact on energy production by reducing the availability of cooling water and by affecting hydropower potential.

Terrestrial ecosystems, soils and forests

Impacts of observed and projected climate change include changes in soil conditions, phenology, species distribution, species interactions, species composition in communities and genetic variability. Changes in soil moisture, such as significant decreases in the Mediterranean region and increases in parts of northern Europe, are having a direct effect on terrestrial ecosystems.

Earlier spring advancement is observed in many plant species, and the pollen season starts earlier and is longer. Many animal groups have advanced their life cycles, including frogs spawning, birds nesting and the arrival of migrant birds and butterflies. The breeding season of many thermophilic insects has lengthened. These trends are expected to continue in the future.

Many species have changed their distribution range, generally northwards and uphill, and these trends are projected to continue. Species migration often lags behind changes in climate owing to intrinsic limitations, habitat use and fragmentation. Some local extinctions of species have been observed. All of these factors may contribute to a decline in European biodiversity, in particular in mountain regions. Climate change is likely to exacerbate the problem of invasive species, as some locations may become more favourable to previously harmless alien species. Climate change is also affecting the interaction of species that depend on each other. It can thus disrupt established interactions, but it can also generate novel ones.

14 % of habitats and 13 % of species of European interest have already been assessed to be under pressure because of climate change. The proportion of habitats threatened by climate change is projected to more than double in the near future. Many species in the Natura2000 network are projected to lose suitable climate niches.

Climate change and increasing CO_2 concentrations are affecting forest ecosystems and their services, as they are causing range shifts of tree species towards higher altitudes and latitudes, are leading to increases in the risk of forest fires, in particular in southern Europe, and are resulting in an increased incidence of forest insect pests. Cold-adapted coniferous tree species are projected to lose large fractions of their ranges to broadleaf species. In general, forest growth is projected to increase in northern Europe and to decrease in southern Europe, but with substantial regional variation.

Economic losses from extreme climate-related events

Climate-related extreme events accounted for almost EUR 400 billion of economic losses in the EEA member countries over the period 1980–2013. This accounts for 82 % of the total reported losses due to extreme events over this period, whereas geophysical events such as earthquakes and volcano eruptions are responsible for the remaining 18 %. The reported economic losses have increased in recent decades. This increase is due primarily to better reporting and to socio-economic trends, such as changes in population, human activities and infrastructure in hazard-prone areas, but the observed increase in heavy precipitation in parts of Europe may have also played a role. Future climate change will affect the frequency and intensity of climate-related extremes and associated losses differently across Europe, but most climate-related hazards are projected to increase across Europe.

The attribution of the observed changes in the number of events and the associated economic losses to specific causes is hampered by large interannual variability of climate-related extreme events, changes in reporting and the implementation of measures to reduce impacts (e.g. flood defences). Policies and actions would be facilitated by better collection of data concerning the economic, social and environmental impacts of weather and climate-related extremes.

Human health

The main health effects of climate change are related to extreme weather events, such as floods and heat waves, changes in the distribution of climate-sensitive diseases and changes in environmental and social conditions.

River and coastal flooding has affected millions of people in Europe in the last decade. Health effects include drowning, injuries, infections, exposure to chemical hazards and mental health consequences.

Heat waves have caused tens of thousands of premature deaths in Europe since 2000. Since the length, frequency and intensity of heat waves are projected to increase substantially in the future, the associated health effects are also projected to increase in the absence of adaptation and physiological acclimatisation. Cold-related mortality is projected to decrease owing to better social, economic and housing conditions in many countries in Europe. The observed relationship between moderate and extreme cold and mortality is complex, and available studies for Europe provide inconclusive evidence of whether or not the projected warming will lead to a further substantial decrease in cold-related mortality.

Observations show a move to higher latitudes and altitudes of specific tick species and their associated vector-borne diseases (Lyme borreliosis and tick-borne encephalitis). Climate change is projected to lead to further northwards and upwards shifts of tick species. Climate change was, and is projected to be, a factor in the recent expansion of the Asian tiger mosquito and a sandfly species in Europe, which can disseminate several diseases (dengue and chikungunya by the Asian tiger mosquito and leishmaniasis by the sandfly species).

Recent outbreaks of vibriosis infections in Baltic Sea states have been linked to unprecedented increases in sea surface temperature.

Quantitative projections of future climate-sensitive health risks are difficult owing to the complex relationship between climatic and non-climatic factors, climate-sensitive diseases and other health outcomes, and future adaptation measures.

Agriculture

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

Recent heat waves, droughts, extreme precipitation and hail have greatly reduced the yield of some crops. Throughout Europe, an increased frequency of extreme events is expected to increase the risk of crop losses and to impose risks for livestock production.

Irrigation demand is projected to increase, in particular in southern Europe, where there is already considerable competition between different water users.

Climate change is projected to improve the suitability of northern Europe for growing crops and to reduce crop productivity in large parts of southern Europe. Projections based on different climate models agree on the direction of the change, but with some variation in its magnitude. Furthermore, effects will differ between crop types and livestock categories, and they are moderated by short- and long-term adaptation efforts.

Energy and transport

The energy demand for heating has decreased in northern and north-western Europe, whereas the demand for cooling has increased in southern and central Europe. The total energy demand in Europe is not expected to change substantially, but significant seasonal shifts and effects on the energy mix are expected, with large regional differences.

Increasing temperatures, changing precipitation patterns, increases in extreme precipitation and possible increases in storm severity and frequency can have an impact on both renewable and conventional electricity energy generators. Most of the projected impacts of climate change will be adverse. For example, further increases in temperature and droughts may limit the availability of cooling water for thermal power generation in summer. However, climate change may have some positive impacts, in particular related to hydropower production in northern Europe.

Energy and transport infrastructures are exposed to substantial risks from the increasing frequency and magnitude of extreme events across Europe. Infrastructures in mountain regions are threatened by geological instability as a result of increased precipitation and melting of mountain permafrost. North-western European countries appear to be ahead of other countries in terms of preparedness regarding coastal energy infrastructure.

The main climate-related events relevant for transport are heat waves in southern and eastern Europe, cold spells and snow in northern Europe and heavy precipitation and floods across all of Europe.

Transport systems in mountain regions, coastal areas and regions prone to more intense rain and snow are generally expected to be most vulnerable to future climate change. Projections suggest that rail transport will face particularly high risks from extreme weather events, mostly because of the projected increase in heavy rain events and the limited routing alternatives. However, there is no comprehensive overview of climate-related risks for transport across Europe owing to widely different methodological approaches in the currently available assessments. The impacts projected by 2050 have been assessed and found to be manageable, provided that proper adaptation measures are taken.

According to a Joint Research Centre (JRC) study, climate-related damage to large investments and critical infrastructures could triple by the 2020s, could increase six-fold by the middle of the century and could increase by more than ten-fold by the end of the century, compared with the 1981–2010 baseline (Forzieri et al., 2015). The greatest increase in damage is projected for the energy and transport sectors, and for EU regional investments in environment and tourism. Southern and south-eastern European countries will be most affected.

Tourism

Climatic suitability for summer and beach tourism is currently best in southern Europe. The touristic attractiveness of northern and central Europe is projected to increase in most seasons. The suitability of southern Europe for tourism will decline markedly during the key summer months, but will improve in other seasons.

The projected reductions in snow cover will negatively affect the winter sports industry in many regions. Regions close to the low elevation limit for winter sports are most sensitive. Therefore, winter sport locations on the southern slopes of the Alps are, on average, more vulnerable than those on the northern slopes.

The projected climate change could have substantial consequences for regions where tourism is an important economic sector. The magnitude of the economic impacts is strongly influenced by non-climatic factors, such as the ability of tourists to adjust the timing of their holidays.

ES.4 Multi-sectoral impacts, vulnerabilities and risks

Summary

Table ES.1 presents an overview of past trends and projected changes for all indicators and for some other climate-sensitive impact domains. The main part of the table shows the predominating direction of observed and projected changes for each indicator and for each of the four main terrestrial regions and regional seas in Europe. Different symbols have been used to reflect situations where the direction of observed or projected changes is not uniform across a region. Empty cells for particular indicators and regions reflect a lack of available information ([1]).

Table ES.1 clearly shows the heterogeneity of climate change impacts across European regions and across indicators and thematic areas. Some indicators exhibit changes in the same direction across Europe (e.g. temperature, absolute sea level), while others show a clear regional pattern (e.g. mean precipitation), and still others show a complex spatial pattern with changes in both directions in individual regions.

The direction of past trends and projections agrees well for most indicators/variables and regions. There are some discrepancies, which are partly due to differences in the consideration of non-climatic factors for observed and projected changes ([2]).

Many indicators include quantitative data on past trends and projections for all regions; others include data on either past trends or projections, and/or data for selected regions only. When data availability is insufficient for showing the direction of past and/or projected changes for all regions, an estimate of the direction of observed and/or projected change averaged over Europe is presented, if possible.

([1]) The regionalisation of land areas generally follows that used in Map ES.1. However, the 'boreal' and 'Arctic' regions are merged into a 'northern' region because insufficient information was available for a separate assessment of all indicators in the Arctic region; the 'mountain' region is not explicitly represented because it is too heterogeneous for making aggregated statements.
The information on regional changes in this table relies primarily on the maps included in the main report; complementary information in the text was used in some cases. The aggregation of the diverse information sources in this report into the common format of Table ES.1 represents the consensus of all authors of this executive summary, which was reached after several iterations, whereby their initially independent assessments were reviewed and made consistent.

([2]) Whenever 'observations' and 'projections' for a region agree, this is represented by a single symbol in the centre of the column rather than two separate symbols. Information under 'observations' reflects past trends in a variable, independent of their attribution. In contrast, information under 'projections' reflects the projected impacts of climate change (and, where relevant, increases in CO_2 concentration) only; these projections do not consider future changes in non-climatic factors or future adaptation policy. Further information on the importance of climatic versus non-climatic factors for a particular indicator, and some information on the scope of adaptation policy, can be found in the main report.

Table ES.1 Key observed and projected climate change and impacts for the main regions in Europe

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		Mediterranean			
				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 magnitude 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			↗→	→↘	↗↘	↗→	↗↘			
3.3	**Cryosphere**												
3.3.2	Arctic and Baltic sea ice	See end of table											
3.3.3	Greenland and Antarctic ice sheets	Mass	No	↘									
3.3.4	Glaciers	Mass	No	↗↘	→↘			↘		↘			
3.3.5	Snow cover	Duration/amount	No									↘	
4	**Climate change impacts on environmental systems**												
4.1	**Oceans and marine environment** (see end of table)												
4.2	**Coastal zones**												
4.2.2	Global and European sea level	Absolute sea level	No	↗		↗		↗		↗→			
		Relative sea level	No	↗↘		↗		↗		↗→	↗		
		Coastal flooding frequency	Variable		↗↘		↗		↗		↗		
4.3	**Freshwater systems**												
4.3.2	River flows	Mean flow (near-natural rivers)	Domain	↗		↗→		↗↘		↘			
4.3.3	River floods	Frequency and magnitude	Trend		↗↘	↗→	↗		↗→		↗↘	↗	
4.3.4	Meteorological and hydrological droughts	Frequency and severity of meteorological droughts	Domain	↗↘	↘	↗↘			↗↘	↗↘	↗		
		Minimum river flow	Domain		↗		↘		↗↘		↘		
4.3.5	Water temperature	Lake and river temperature	No	↗		↗		↗		↗			
4.4	**Terrestrial ecosystems, soil and forests**												
4.4.2	Soil moisture	Summer soil moisture	No	↗→		→↘	↗↘	→↘	↗↘	→↘	↘		
4.4.3	Phenology of plant and animal species	Day of spring events	No					↘				↘	
4.4.4	Distribution shifts of plant and animal species	Latitude and altitude	Domain	↗		↗		↗→	↗	↗→	↗		
4.4.5	Forest composition and distribution	Latitude and altitude	Domain									↗→*	↗
4.4.6	Forest fires	Area burnt	Trend							→↘	↗		↗
		Forest fire risk index	Domain	→↘	↗→	↗↘	↗→	↗→	↗	↗↘	↗		
4.4.7	*Forest pests and diseases*	*Occurrence of insect pests*	Domain	↗→		↗→		↗→		↗→			↗↘*
5	**Climate change impacts on society**												
5.1	**Impacts of climate-related extremes**												
5.1.3	Economic losses from climate-related extremes	Costs	Trend									↗	
5.2	**Human health**												
5.2.3	Floods and health	Mortality and morbidity	Variable				↗						↗
5.2.4	Extreme temperatures and health	Heat-related mortality	Trend						↗		↗	↗	
		Cold-related mortality	Variable										↘
5.2.5	Vector-borne diseases	People infected	Trend									↗→*	
5.2.6	Water- and food-borne diseases	People infected (vibriosis)	Trend									↗→*	↗

Table ES.1 Key observed and projected climate change and impacts for the main regions in Europe (cont.)

<table>
<tr><th colspan="14">Direction of observed and projected climate change and impacts for the main regions in Europe</th></tr>
<tr><th rowspan="3">Section</th><th rowspan="3">Indicator/impact domain</th><th rowspan="3">Variable</th><th rowspan="3">Sensitivity to adaptation policy</th><th colspan="2">Northern</th><th colspan="4">Temperate</th><th colspan="2">Southern</th><th colspan="2" rowspan="2">European average</th></tr>
<tr><th colspan="2">Boreal and Arctic</th><th colspan="2">Atlantic</th><th colspan="2">Continental</th><th colspan="2">Medi-terranean</th></tr>
<tr><th>Obs</th><th>Proj</th><th>Obs</th><th>Proj</th><th>Obs</th><th>Proj</th><th>Obs</th><th>Proj</th><th>Obs</th><th>Proj</th></tr>
<tr><td>5.3</td><td colspan="13">Agriculture</td></tr>
<tr><td>5.3.2</td><td>Growing season for agricultural crops</td><td>Duration</td><td>No</td><td colspan="2">↗</td><td colspan="2">↗</td><td colspan="2">↗</td><td colspan="2">↗→</td><td></td><td></td></tr>
<tr><td>5.3.3</td><td>Agrophenology</td><td>Day of spring events</td><td>Domain</td><td colspan="2">↘</td><td colspan="2">↘</td><td colspan="2">↘</td><td colspan="2">↘</td><td></td><td></td></tr>
<tr><td>5.3.4</td><td rowspan="2">Water-limited crop yield</td><td>Average yield</td><td>Variable</td><td></td><td>↗</td><td></td><td>↗↘</td><td></td><td>→</td><td></td><td>↘</td><td></td><td></td></tr>
<tr><td></td><td>Adverse climatic conditions</td><td>Domain</td><td></td><td>↗</td><td></td><td>↗</td><td></td><td>↗→</td><td></td><td>↗→</td><td></td><td></td></tr>
<tr><td>5.3.5</td><td>Crop water demand</td><td>Water deficit</td><td>Domain</td><td></td><td></td><td colspan="2">↗↘</td><td colspan="2">↗↘</td><td>↗↘</td><td>↗→</td><td></td><td></td></tr>
<tr><td>5.4</td><td colspan="13">Energy</td></tr>
<tr><td>5.4.2</td><td rowspan="2">Heating and cooling degree days</td><td>Heating degree days</td><td>No</td><td colspan="2">↘</td><td colspan="2">↘</td><td colspan="2">↘</td><td colspan="2">↘→</td><td></td><td></td></tr>
<tr><td></td><td>Cooling degree days</td><td>No</td><td>→</td><td>↗→</td><td colspan="2">↗→</td><td>↗→</td><td>↗</td><td colspan="2">↗</td><td></td><td></td></tr>
<tr><td>5.4.4</td><td>Electricity production</td><td>Production potential</td><td>Domain</td><td></td><td>↗</td><td></td><td>↗↘</td><td></td><td>↘→</td><td></td><td>↘</td><td></td><td></td></tr>
<tr><td>5.5</td><td colspan="13">Transport</td></tr>
<tr><td>5.5.2</td><td>Impacts of climate and weather extremes</td><td>Costs of adverse weather events</td><td>Domain</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>↗→ *</td></tr>
<tr><td>5.6</td><td colspan="13">Tourism</td></tr>
<tr><td>5.6.2</td><td>Summer and beach tourism</td><td>Attractivity (summer season)</td><td>Domain</td><td></td><td>↗</td><td></td><td>↗↘</td><td></td><td>↗↘</td><td></td><td>↘</td><td></td><td></td></tr>
<tr><td>5.6.3</td><td>Winter and mountain tourism</td><td>Winter sport potential</td><td>Domain</td><td></td><td>↘→</td><td></td><td></td><td></td><td>↘</td><td></td><td></td><td></td><td></td></tr>
<tr><td>6</td><td colspan="13">Multi-sectoral vulnerability and risks</td></tr>
<tr><td>6.3</td><td>Projected economic impacts</td><td>Welfare</td><td>Variable</td><td></td><td>→</td><td></td><td>→</td><td></td><td>↘</td><td></td><td>↘</td><td></td><td></td></tr>
<tr><th></th><th></th><th></th><th></th><th colspan="2">Arctic Ocean</th><th colspan="2">Atlantic and North Sea</th><th colspan="2">Baltic Sea</th><th colspan="2">Mediterra-nean and Black Sea</th><th colspan="2">European seas average</th></tr>
<tr><td>3.3.2</td><td>Arctic and Baltic sea ice</td><td>Extent</td><td>No</td><td colspan="2">↘</td><td></td><td></td><td colspan="2">↘</td><td></td><td></td><td></td><td></td></tr>
<tr><td>4.1</td><td colspan="13">Oceans and marine environment</td></tr>
<tr><td>4.1.2</td><td>Ocean acidification</td><td>Acidity</td><td>No</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="2">↗</td></tr>
<tr><td>4.1.3</td><td>Ocean heat content</td><td>Heat content</td><td>No</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="2">↗</td></tr>
<tr><td>4.1.4</td><td>Sea surface temperature</td><td>Temperature</td><td>No</td><td colspan="2">↗</td><td colspan="2">↗</td><td colspan="2">↗</td><td colspan="2">↗</td><td></td><td></td></tr>
<tr><td>4.1.5</td><td>Range shifts of marine species</td><td>Latitude (migration and immigration)</td><td>No</td><td>↗</td><td></td><td>↗</td><td></td><td></td><td></td><td>↗</td><td></td><td></td><td>↗</td></tr>
<tr><td>4.1.5</td><td>Fisheries</td><td>Catch potential</td><td>Domain</td><td>↗↘</td><td>↗</td><td>↗↘</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>4.1.6</td><td>Ocean oxygen content</td><td>Number of dead zones</td><td>Trend</td><td></td><td></td><td></td><td></td><td colspan="2">↗</td><td></td><td></td><td colspan="2">↗</td></tr>
</table>

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.

For 34 out of the 49 variables assessed, changes in a given direction can be described as either beneficial (green) or adverse (red). For the other 15 variables (black), a given change can be (predominantly) beneficial in one region and (predominantly) adverse in another region, depending on climatic, environmental and other factors.

Some variables exhibit changes that are either beneficial or adverse across all or most regions; other indicators show a more complex regional pattern of beneficial and adverse changes. On a more aggregate level, most sectors covered by several indicators and/or variables exhibit both beneficial and adverse changes in most regions (e.g. agriculture, energy and tourism). Sectors with predominantly adverse impacts for most regions are coastal zones and human health; none of the sectors show predominantly beneficial impacts of climate change.

The table also specifies whether an indicator and variable ('sub-indicator') are sensitive to adaptation policies. Out of the 49 variables assessed, seven include observed *trends* that are sensitive to actual or potential adaptation policies (in a broad sense); five further *variables* were assessed as being sensitive to adaptation policies, but only information on projections is presented here; another 15 variables represent impact *domains* that are sensitive to adaptation policies, but the particular variable is not (e.g. because of data limitations). The remaining 22 variables are *not* sensitive to adaptation policies (e.g. climate variables). Out of the seven variables with trends that are potentially sensitive to adaptation policies, three show trends for one out of four regions only, and the other ones show trends for the European average only. Thus, the current information base is clearly insufficient for assessing the effectiveness of adaptation policies across Europe in any of the sectors considered here.

Map ES.1 shows examples of key observed and projected changes in climate and their impacts for the main biogeographic regions in Europe ([3]). The inclusion of specific climatic changes and impacts reflects a qualitative assessment of their relative importance for the majority of a particular regions. However, there is considerable variation within each region, and impacts mentioned for a specific region can also occur in other regions, where they are not mentioned.

Key climate change impacts and vulnerabilities in European regions

The following text presents a selection of the key impacts and vulnerabilities for the main biogeographical regions in Europe. For further information about these regions, see Map ES.1.

Arctic region (northern Europe)

The Arctic environment will, because of the faster than average rise in air and sea temperatures, undergo major changes, which will affect both ecosystems and human activities. Habitats for flora and fauna (including sea ice, tundra and permafrost peat lands) have already been partially lost. Arctic vegetation zones are likely to shift further, having wide-ranging secondary impacts. Some species of importance to Arctic people and species of global significance are declining. Marine ecosystem acidification may become a serious threat, as acidification can progress more rapidly in Arctic oceans as a result of low temperatures and the considerable influx of freshwater. Climate change is the most far-reaching and significant stressor on Arctic biodiversity.

Indigenous people with traditional livelihoods live in the Arctic. Many of these livelihoods depend directly on ecosystem services, and local communities are already experiencing climate change impacts. Traditional livelihoods, such as reindeer herding, that are under pressure from various socio-economic and political developments may suffer further from climate change impacts.

Infrastructures are at risk from sea level rise and thawing of Arctic permafrost, which poses challenges to communities and to economic activities such as forestry and mineral extraction. Conditions for shipping across the Arctic Ocean and exploitation of non-renewable natural resources may become more favourable in the future, but these new opportunities are associated with numerous risks for the environment. Utilising Arctic oil and natural gas resources would challenge the transition to a low-carbon society, as it is recommended that two-thirds of known global fossil resources remain in the ground if the 2 °C warming limit of the UNFCCC is to be met.

([3]) The regionalisation in Map ES.1 is based on the map of biogeographical regions set up under the Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention). The following changes were made to reflect limited data availability for some regions: 'Continental Europe' also includes the 'Pannonian' and 'Steppic' regions; the 'Mediterranean' region also includes the Black Sea region; 'mountain areas' comprise the 'Alpine' and 'Anatolian' regions; and the 'Macaronesian' region is not explicitly shown.

Map ES.1 **Key observed and projected climate change and impacts for the main biogeographical regions in Europe**

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

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

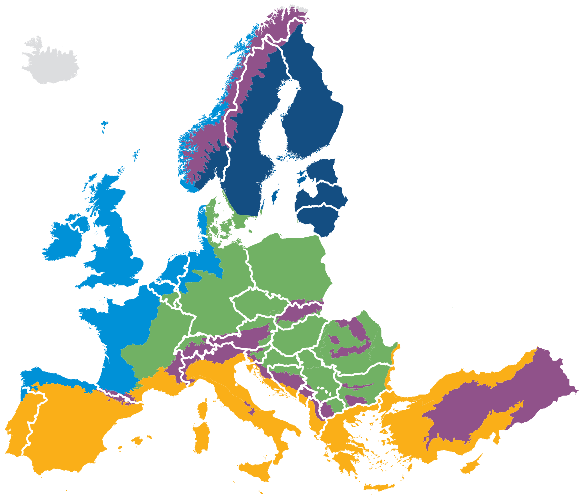
Mountain regions
Temperature rise larger than European average
Decrease in glacier extent and volume
Upward shift of plant and animal species
High risk of species extinctions
Increasing risk of forest pests
Increasing risk from rock falls and landslides
Changes in hydropower potential
Decrease in ski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

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

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



Boreal region (northern Europe)

Projections suggest that there will be a larger than average temperature increase, in particular in winter, an increase in annual precipitation and river flows, less snow and greater damage by winter storms in this region. Climate change could offer some opportunities in northern Europe, including increased crop variety and yields, enhanced forest growth, higher potential for electricity from hydropower, lower energy consumption for heating and possibly more summer tourism. However, more frequent and intense extreme weather events are projected to have an adverse impact on the region, for example by making crop yields more variable and by increasing the risk from forest pests and forest fires. Heavy precipitation events are projected to increase, leading to increased urban floods and associated impacts.

Atlantic region (north-western Europe)

Coastal flooding has had an impact on low-lying coastal areas in north-western Europe in the past. These risks are expected to increase as a result of sea level rise and potentially stronger storm surges, with North Sea countries being particularly vulnerable. Stronger extreme precipitation events, in particular in winter, are projected to increase the frequency and intensity of winter and spring river flooding, urban floods and associated impacts. The risk of severe winter storms, and possibly of severe autumn storms, is projected to increase.

Continental region (central and eastern Europe)

Increasing heat extremes are a key hazard in central and eastern Europe. Together with reduced summer precipitation, they can increase drought risk, health risks and energy demand in summer. The intensity and frequency of river floods in winter and spring is projected to increase in various regions as a result of increases in winter precipitation. Climate change is also projected to lead to an increased risk of river floods, higher crop-yield variability and an increased occurrence of forest fires.

Mediterranean region (southern Europe)

The Mediterranean region is facing decreasing precipitation and increasing temperatures, in particular in summer. The main impacts are decreases in water availability and crop yields, increasing risks of droughts and forest fires, biodiversity loss and adverse impacts on human health and well-being and on livestock. Environmental water flows, which are important for aquatic ecosystems, are threatened by climate change and by socio-economic developments. Overall, the competition between different water users is expected to increase. The observed invasion and survival of alien species in the Mediterranean Sea is partly due to the warming trend in sea surface temperature. The energy sector will be affected by decreasing water availability and increasing energy demand for heating, in particular in summer. The suitability for tourism will decline markedly during the key summer months, but will improve in other seasons. The Mediterranean region is a hotspot of climate change impacts, having the highest number of economic sectors severely affected. It is also particularly vulnerable to the spill-over effects of climate change impacts in neighbouring regions, in particular related to disruptions in agricultural trade and to migration flows.

European Union Outermost Regions and the Overseas Countries and Territories

The European Union Outermost Regions and the Overseas Countries and Territories are particularly vulnerable to climate change impacts, in particular to sea level rise and extreme weather events. Water resources are highly sensitive to sea level rise because of the risk of saltwater intrusions. The very rich biodiversity and high concentration of endemic species are sensitive to changes in temperature and precipitation and to the introduction or increase of pests and invasive species. The high concentration of population, socio-economic activities and infrastructures in low-lying coastal zones make these regions and territories very vulnerable to sea level rise and coastal flooding. The economic dependence on a small number of products and services (e.g. fishing and tourism) make them highly vulnerable to any potential changes.

Mountain regions

Many mountain regions are experiencing a particularly large increase in temperature, as well as reduced snow cover, loss of glacier mass, thawing of permafrost and changing precipitation patterns, including less precipitation falling as snow. Mountain ecosystems are particularly vulnerable to climate change. Impacts include a shift in vegetation zones and extensive biodiversity loss. Plant and animal species living close to mountain tops face the risk of becoming extinct owing to the inability to migrate to higher altitudes.

Most mountain regions are expected to be adversely affected in relation to their water resources. The retreat of the vast majority of glaciers also affects water availability in downstream areas. Additional impacts include a reduced potential for winter tourism, in particular in lower lying regions, and increasing risks to infrastructure and settlements from floods, landslides and rock falls in some regions. Hydropower potential is projected to change, with positive impacts in some regions (e.g. Scandinavia) and negative impacts in others (e.g. the Alps).

Coastal zones and regional seas

Coastal zones across Europe are facing an increasing risk of flooding from rising sea levels and a possible increase in storm surges. Climate change is leading to major changes in marine ecosystems as a result of warming and ocean acidification. It can also exacerbate oxygen depletion from eutrophication, leading to dead zones. Impacts on fisheries can be both adverse and beneficial, with the highest risks faced by coastal fisheries with limited adaptation potential. Increasing sea surface temperatures can also adversely affect water quality (e.g. through algal blooms) and facilitate the spread of water-borne diseases, such as vibriosis.

Cities and urban areas

The climate resilience of Europe's cities, which are inhabited by almost three-quarters of the population, is decisive for their functioning and for Europe's growth, productivity and prosperity.

Cities face specific climate threats. Having a high proportion of elderly people makes cities sensitive to heat waves and other climatic hazards. The urban heat island effect exacerbates the impacts of heat waves and is increasingly also affecting cities in central and north-western Europe. High soil sealing and urban sprawl in combination with more extreme precipitation events and sea level rise increase the risk of urban flooding. Many cities have continued to spread noticeably into areas potentially prone to river floods, thus increasing their exposure to floods. Urban sprawl with low-density housing into previously wild land has increased the risk of forest fires in many residential areas over the last decades, in particular around cities in southern Europe.

Socio-economic scenarios for Europe

A comprehensive assessment of the vulnerability of regions, sectors, population groups and infrastructure to climate change needs to consider potential changes in socio-economic factors, as well as multiple interdependencies across climate-sensitive sectors.

Population size in eastern Europe is projected to decrease considerably during the 21st century. For western Europe, some scenarios project increases throughout the century, while others project slight increases until the middle of the century followed by a decline thereafter, and still others assume a continuous decline throughout the 21st century. The population is projected to age substantially in both western and eastern Europe.

Urbanisation is projected to increase further. The difference between scenarios in the proportion of the population that is urban is relatively large in eastern Europe; in western Europe, the urban population is expected to increase to above 90 % in most countries and scenarios.

Available projections assume future growth in income per capita, but the magnitude of this growth varies significantly between scenarios, particularly in western Europe. The current fundamental gap in gross domestic product (GDP) per capita between eastern and western Europe is expected to significantly reduce throughout the century, but not to vanish completely.

Capacities to cope with the consequences of climate change appear to be increasing, but the current higher capacity in central and north-western parts of Europe than in southern and some eastern parts of Europe is expected to prevail to some degree. Opportunities for technological and social innovations are greater for scenarios that assume well-functioning governance and international cooperation.

Multi-sectoral vulnerabilities and projected costs

The water, agriculture, forestry and biodiversity sectors and domains show strong interdependencies with each other and with non-climatic developments, such as changing land-use patterns and population change. South-eastern and southern Europe are projected to be hotspot regions, based on the high number of sectors and domains severely affected. Regarding ecosystem services, the Alps and the Iberian Peninsula are also hotspots.

An assessment considering several climate hazards, including droughts, fires and sea level rise, has identified southern Europe, but also coastal areas and floodplains in western Europe, as multi-sectoral hotspots. The greatest challenges appear to be concentrated in south-eastern and southern parts of Europe.

Estimates of the projected economic impacts of climate change in Europe are emerging, but the coverage remains partial and there is considerable uncertainty. A JRC study indicates that there will be potentially high economic costs, even for modest levels of climate change, and these costs rise significantly for scenarios of greater levels of warming (Ciscar et al., 2014). Annual total damages from climate change in the EU could be around EUR 190 billion (with a net welfare loss estimated to be equivalent to 1.8 % of current GDP) by the end of the century under a reference scenario. There is a strong distributional pattern of costs, with notably higher impacts in southern Europe.

In recent years, more information has become available on the costs and benefits of adaptation, especially for coastal areas, water management, floods, agriculture and the built environment. The focus of these studies has been on national and regional rather than on pan-European estimates.

Europe's vulnerability to climate change impacts outside Europe

Climate change is having an impact on all world regions. Several recent studies have suggested that climate change will have much stronger negative impacts on the global economy than previously assumed, with poor countries being disproportionally affected. 'The Global Risks Report 2016' indicates that the most impactful risk in the years to come was found to be a failure in climate change mitigation and adaptation (WEF, 2016).

Europe is susceptible to spill-over effects from climate change impacts occurring outside European territories through six major pathways: the trade of agricultural commodities, the trade of non-agricultural commodities, infrastructure and transport, geopolitics and security risks, human migration and finance. The strongest evidence for Europe's vulnerability to cross-border impacts are the economic effects seen as a result of climate-related price volatilities and disruptions to transportation networks.

Recent climate extremes outside Europe have already had a negative impact on Europe. One example of global price volatilities caused by climate extremes is the Russian heat wave in 2010, which destroyed a substantial area of crops, thereby negatively affecting Russia's grain harvest. This led to an export ban on wheat by the Russian government, which contributed to a substantial increase in global wheat prices. An example of indirect effects through supply chains to Europe is the shortage of hard drives and the associated increase in price levels caused by a severe flood event in Thailand in 2011. An example of effects of climate-related hazards on infrastructure outside Europe is Hurricane Katrina (2005), which destroyed large parts of the port of New Orleans, causing a temporary shortage in global oil supply and thereby triggering a temporary increase in the global oil price. A potentially major climate-related impact on global trade relates to the opening of Arctic sea routes following the shrinkage of the Arctic sea ice.

The Mediterranean region has been identified as particularly vulnerable to shocks in the flow of agricultural commodities, owing to, among others, a high dependency on imports from outside Europe, whereas small, open and highly developed European economies are regarded as particularly vulnerable to shocks in the flow of non-agricultural commodities.

Climate change in North African regions, such as the Sahel and the Maghreb, as well as in the Middle East, may increase the strategic importance of these regions for Europe, with respect to both potential climate-induced human migration flows, and geopolitical and security considerations. The links between different triggering factors is extremely complex. An unprecedented drought that has affected parts of the Middle East in recent years has been suggested as one among many drivers (e.g. economic situation, governance) shaping local conflicts that triggered the Syrian civil war, which ultimately led to the current substantial increase in refugee flows to Europe.

European vulnerability to cross-border effects is expected to increase in the coming decades, but quantitative projections are not yet available.

ES.5 Possible ways forward on adaptation

The SOER 2015 highlights that, to achieve the 2015 vision of the 7th EAP, fundamental transitions are needed in key systems such as the transport, energy, housing and food systems. Four approaches are mentioned to enhance progress: mitigation through resource-efficient technological innovations; adaptation, by increasing resilience; avoiding harm to people's health and well-being and to ecosystems through precautionary and preventative action; and restoring and enhancing natural resources.

Adapting to the many changes that European society faces, as mentioned above, is a challenge, but it is also an opportunity for synergies and benefits if Europe implements adaptation measures in a coherent way. Achieving the desired policy coherence needs continued efforts to mainstream adaptation in many environmental and sectoral policies, regarding both policy development and implementation, and working towards similar goals. Enhancing the synergies between disaster risk reduction and climate change adaptation and including adaptation considerations in existing and new major infrastructural investments are particularly important. There is also a need to address interdependencies across sectors regarding major infrastructures (e.g. transport, electricity production and communication), for example through 'stress tests'.

A related challenge is to ensure the effectiveness, efficiency and coherence of action across the various levels of governance. EU adaptation policy should take into account national strategies and plans, as well as actions at transnational and city levels.

Adaptation policy responses must be flexible and tailor-made to address regional and local conditions and needs and must also take into account the progress made in the scientific understanding of disaster risks, decadal climate variability, and long-term climate and socio-economic changes. This understanding is evolving and lessons are being learned from implementing actions. It is important to adopt an 'adaptive management' approach, which means adjusting plans to these conditions as they unfold, taking account of the uncertainty on future developments and constantly updating adaptation policy with new information from monitoring, evaluation and learning.

Flexibility can also be advanced by using different types of adaptation measures. Implementing a combination of 'grey' (i.e. technological and engineering solutions), 'green' (i.e. ecosystem-based approaches) and 'soft' (i.e. managerial, legal, policy and market-based approaches) adaptation options is often a good way to deal with the interconnections between natural systems and social systems.

The involvement of stakeholders is important in creating a sense of 'ownership' in adaptation policy, a critical factor in the success of adaptation implementation. Stakeholder involvement also helps to improve the coherence of adaptation actions and builds adaptive capacity in the wider society. Multi-level governance bridges the gaps between the different levels of policy and decision-making and provides opportunities for ensuring that key actors are involved.

There is limited information about the vulnerability of and risks faced by businesses and about adaptation measures being taken by the private sector. This challenge could be addressed by the private sector through assessments of their vulnerabilities, including in their value and supply chains, and by implementing adaptation actions. These activities can be supported by emerging climate change and adaptation services. The development and implementation of innovative solutions for adaptation can provide business opportunities in many different sectors.

Incremental adaptation, such as improving existing flood defences and increasing existing water reservoirs, builds on existing adaptation measures and known solutions by improving on them, often based on proven knowledge gained over several decades. Incremental adaptation often focuses on individual measures, as appropriate, and as opportunities appear. Measures are relatively quick to put in place and can often deal sufficiently and effectively with short- and medium-term challenges.

Incremental adaptation may be sufficient to deal with most short- and medium-term challenges, but transformational adaptation is often required to address the long-term challenges of climate change. Transformational adaptation involves managing more radical change, rather than protecting or restoring a certain environmental or social state. As transformations require more fundamental changes, it is important to start considering them now and discussing possible pathways with stakeholders, in parallel to developing and implementing incremental options to address vulnerable hotspots.

Transformative adaptation follows a broad and systemic approach and addresses the root causes of vulnerability to climate change, which is often the result of human actions, such as settling in risk-prone areas, inadequate building design or other behaviours that aggravate the impacts of climate change. For example, the designs of a city, its buildings and its infrastructures are supposed to last for decades or even centuries. Transformative adaptation requires the rethinking of city planning and building to prepare for future climatic conditions. It may involve, for example, the redesign of parks and other open spaces to accommodate storm water, new building design to better cope with heat waves and developing transport infrastructure that is robust against extreme events. The transformative approach seeks to integrate adaptation with other aspects of urban development, offering the opportunity of a better functioning city and improved quality of life (EEA, 2016b).

Countries and cities, with a few exceptions, have not yet implemented comprehensive adaptation approaches that combine incremental and transformative actions, although some have taken transformative steps. In the future, further actions will be required, combining different types of actions and learning from experiences that are accumulating across EU, transnational, national and urban levels. Such learning will benefit from increasing activities at various governance levels in monitoring, reporting and evaluation. Sharing experiences and learning about the use of monitoring and evaluation results will further improve adaptation policy and practice (EEA, 2015a).

ES.6 Strengthening the knowledge base

The length of time series for, the geographical coverage of and the quality of climate change data and indicators have improved over recent years as a result of European and global efforts such as the Global Climate Observing System. Atmospheric and ocean observations are the most developed, but an integrated approach to terrestrial observations is still lacking.

Climate change impact indicators have also improved over recent years at EU and national levels, and many countries have performed climate change impact, vulnerability and/or risk assessments. However, improvements in such assessments are feasible, e.g. by better addressing indirect and cascading effects. Furthermore, there are no agreed common methods for indicator sets across Europe, which makes it difficult to compare information across countries. It can be useful to explore how existing thematic and sectoral EU legislation and policies could be used to improve data and indicators on climate change impacts.

Climate change services are emerging at national and EU levels (e.g. the Copernicus Climate Change Service and the Joint Programming Initiative 'Connecting Climate Knowledge for Europe'). They provide climate data and information, such as essential climate variables, reanalyses, observations, seasonal forecasts and long-term projections. Emerging adaptation services (at national and EU levels, e.g. the Climate Knowledge and Innovation Community) provide complementary information, e.g. on vulnerability and cost–benefit assessments, policies, tools and case studies. Climate change services and adaptation services are expected to become increasingly integrated in the future, thereby delivering the services needed by the intended users. Furthermore, enhanced knowledge and experiences facilitate the development, prioritisation and implementation of adaptation options, and the integration of them flexibly into other policies.

An increasing number of countries, and also city networks, are developing systems for the monitoring, reporting and evaluation of adaptation policies. An approach that combines quantitative indicators and qualitative information, including process-based indicators, can be a strong basis for assessments. Only a few countries have so far established such approaches.

The European Commission has developed a process-based 'adaptation preparedness scoreboard' to assess the progress of Member States, which will be included in its evaluation of the EU Adaptation Strategy, which is due to be published in 2018. There is an increasing need to complement this scoreboard with quantitative information at the EU level.

As part of the Sendai Framework for Disaster Risk Reduction, the finalisation of a set of indicators to measure progress in its implementation is planned by the end of 2016. Countries, including EU Member States, need to establish national databases of disaster impacts on ecosystems, human health and the economy. The Sendai Framework indicators for weather- and climate-related hazards are expected to be very relevant and useful for climate change adaptation.

Overall, the main knowledge gaps are regarding national and sectoral impact, vulnerability and adaptation assessments; economic damages and losses; costs and benefits of adaptation; options for effectively mainstreaming adaptation into public and private investments; adaptation services; interdependencies, synergies and trade-offs between policy objectives; and monitoring systems and tools. EU-funded research, in particular through Horizon 2020, and national research should address these adaptation knowledge gaps. However, transformative adaptation will require innovations and structural change, as well as reflexive learning from experience. The Horizon 2020 programme aims to facilitate such changes.