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Climate change, impacts and vulnerability in Europe 2012

An indicator-based report

Summary

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An indicator-based report

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Executive summary

Key messages

- Climate change (increases in temperature, changes in precipitation and decreases in ice and snow) is occurring globally and in Europe; some of the observed changes have established records in recent years.
- Observed climate change has already led to a wide range of impacts on environmental systems and society; further climate change impacts are projected for the future.
- Climate change can increase existing vulnerabilities and deepen socio-economic imbalances in Europe.
- Damage costs from natural disasters have increased; the contribution of climate change to these costs is projected to increase in the future.
- The combined impacts of projected climate change and socio-economic development can lead to high damage costs; these costs can be reduced significantly by mitigation and adaptation actions.
- The causes of the most costly climate impacts are projected to differ strongly across Europe.
- On-going and planned monitoring and research at national and EU level can improve assessments of past and projected impacts of climate change, thereby enhancing the knowledge base for adaptation.

This European Environment Agency (EEA) report presents information on past and projected climate change and related impacts in Europe, based on a range of indicators. The report also assesses the vulnerability of society, human health and ecosystems in Europe and identifies those regions in Europe most at risk from climate change. Furthermore, the report discusses the principle sources of uncertainty for the indicators and notes how monitoring and scenario development can improve our understanding of climate change, its impacts and related vulnerabilities.

Why such a report?

The United Nations Framework Convention on Climate Change (UNFCCC) has agreed to limit the increase in global mean temperature since pre-industrial times to less than 2 °C, in order to prevent the most severe impacts of climate change. Current global actions to reduce greenhouse gas emissions ('mitigation') are insufficient to constrain the temperature increase to 2 °C, and global warming could be well above 2 °C by 2100. Even if the 2 °C limit is kept, substantial impacts on society, human health and ecosystems are projected to occur. Adaptation to and mitigation of climate change are therefore both needed.

The European Commission has initiated various actions to integrate and mainstream adaptation into EU sectoral policies following the publication of the White Paper on adaptation to climate change in 2009. Furthermore, many countries in Europe have already adopted national adaptation strategies and some have followed up with specific action plans. The European Commission plans publishing its European Adaptation Strategy in 2013, which will include further proposals for adaptation actions across the EU.

This report aims at providing a strong knowledge base for the development and implementation of adaptation strategies and actions at both national and EU levels. The indicators presented here are also accessible via the EEA indicator management system and the European Climate Adaptation Platform (Climate-ADAPT; http://climate-adapt.eea.europa.eu). Early in 2013 the EEA will publish a dedicated report on adaptation, which will assess actions to adapt to climate change at European, national and sub-national levels.

Developing previous assessments further

This 2012 report follows earlier indicator-based assessments of climate change impacts and vulnerability published by the EEA in 2004 and 2008. The amount and quality of the information underlying the 2012 report has increased compared to the previous report of 2008.

New elements in the 2012 report include:

- use of a revised set of criteria for the selection of indicators, including policy relevance, strength of causal links between climate change and observed impacts, methodological soundness, data quality, availability of long periods of observations, and information on robustness and uncertainty;
- several new and extended indicators, for example on storms and storm surges, Baltic Sea ice, ocean acidification and ocean heat content, crop productivity, floods and health, and energy demand;
- information from several EU-funded projects that assess the impacts, vulnerability and costs of climate change across Europe considering also other socio-economic developments.

Where feasible, indicators cover the 32 member countries of the EEA. In some cases, indicators cover fewer countries due to the lack of European-wide data or to limited geographical relevance (e.g. glaciers). The indicators supporting the assessment cover a wide range of themes and sectors. They are based on data from in situ and satellite monitoring programmes, national and EU research programmes, and global initiatives.

Main findings of the report

Climate change (increases in temperature, changes in precipitation and decreases in ice and snow) is occurring globally and in Europe; some of these observed changes have established records in recent years

Compared to the preindustrial level (end of the 19th century), mean temperature and the frequency and length of heat waves have increased across Europe. The average temperature over land in Europe in the last decade was 1.3 °C warmer than the preindustrial level, which makes it the warmest decade on record. Over the same period precipitation has increased in northern and north-western Europe but it has decreased in southern Europe. Regarding storms, the observations do not show a clear trend. Storm frequency was increasing from the 1960s to 1990s, but followed by a decrease to the present.

The melting of the Greenland ice sheet has been accelerating since the 1990s. Exceptional melting was recorded in the summer of 2012. Arctic sea ice extent and volume have been decreasing much faster than previously projected. Record low sea ice cover was observed in 2007, 2011 and 2012 and can be equated to roughly half the size of the normal minimum extent in the 1980s. Snow cover has been decreasing, the vast majority of glaciers in Europe have been receding, and most permafrost soils have been warming.

Observed climate change has already led to a wide range of impacts on environmental systems and society

The following impacts of climate change have been observed:

- **Coasts and European seas**: overall rise in sea levels globally and across most of Europe's coasts (with variations due to local land movement and other factors); increase in ocean acidification; increase in sea surface temperature and ocean heat content; earlier seasonal appearance of various marine species; northward expansion of some fish and plankton species.
- **Freshwater systems**: decrease in river flows in southern and eastern Europe (in particular in summer) and increase in other regions (in particular in winter); increases in the reported number of flood events (mainly due to land-use changes and better reporting); increase in the frequency and intensity of droughts (in particular in southern Europe); increase in water temperature in rivers and lakes; northwards movement of cold-water species; earlier seasonal appearance of phytoplankton and zooplankton blooms.

- **Terrestrial biodiversity and ecosystems**: earlier occurrence of spring seasonal events and later occurrence of autumn seasonal events in plants and animals; lengthening of breeding seasons; northwards and uphill movement of many plant and animal species, but the migration rate of many species is insufficient to keep pace with the speed of climate change; establishment of warm-adapted alien plant species; many habitats of European interest (EU Habitats Directive) are potentially threatened by climate change over their natural range in Europe.

- **Agriculture:** northward expansion of areas suitable for several crops; earlier flowering and harvest dates in cereals; reduced yield of some crops due to heat waves and droughts (mostly in central and southern Europe), but increased yields of other crops (mostly in northern Europe); increased water demand for irrigation (in southern and south-western Europe).

- **Forests and forestry**: reduction in forest growth due to storms, pests and diseases in some central and western areas of Europe; increase in the number of forest fires in the Mediterranean region between 1980 and 2000 and a decrease thereafter.

- **Energy**: reduced demand for heating (particularly in northern and north-western Europe) but increased demand for cooling (particularly in southern Europe).

- **Human health**: tens of thousands of premature deaths due to the extreme 2003 summer heat-wave; thousands of premature deaths per year due to tropospheric ozone (but the contribution of climate change is difficult to quantify); increased number of people affected by river and coastal flooding; northward and upward movement of tick species and related increased risk of transmission of vector-borne diseases.

Further climate change impacts are projected for the future

Observed impacts of climate change are projected to continue due to further climate change. The level of future impacts depends on the magnitude of climate change and on socio-economic and environmental factors. Socio-economic developments can either aggravate or reduce the projected impacts of climate change. Future impacts can be substantially reduced by an ambitious global mitigation policy and by targeted adaptation actions.

Climate change can increase existing vulnerabilities and deepen socio-economic imbalances in Europe

Existing socio-economic vulnerabilities may be exacerbated by the impacts of climate change. There are significant differences in the economic, technical, and institutional capacity to cope with and adapt to climate change across Europe. When impacts of climate change affect regions with low adaptive capacity, the consequences can be severe. An integrated assessment of European regions' vulnerability to climate change suggests that climate change may negatively affect the territorial cohesion in Europe by deepening existing socio-economic imbalances.

Damage costs from natural disasters have increased; the contribution of climate change to these costs is projected to increase in the future

Hydro-meteorological events such as floods and storms account for around two thirds of the damage costs of natural disasters, and these costs have increased since 1980. The observed increase in damage costs from extreme weather events is mainly due to increases in population, economic wealth and human activities in hazard-prone areas and to better reporting. The contribution of climate change to the damage costs from natural disasters is expected to increase in the future due to the projected increase in the intensity and frequency of extreme weather events in many regions.

The combined impacts of projected climate change and socio-economic development can lead to high damage costs

Potentially large damage costs are projected for Europe due to the combined impacts of socio-economic developments and climate change, such as increases in coastal and river flooding, heat waves and energy demand for cooling. Cost estimates for various key sectors (infrastructure, built environment, tourism, transport, and forestry) are either unavailable or fragmentary. There is no consensus on cost estimates for biodiversity and ecosystem services due to the challenge of proper economic valuation. Estimates of the total costs of future climate change on the European economy are currently not available.

The causes of the most costly climate impacts are projected to differ strongly across Europe

The most costly impacts in southern Europe are projected to be increases in energy demand and heat waves, in western Europe coastal flooding and heat waves, in northern Europe coastal and river floods, and in eastern Europe river floods.

The damage costs from climate impacts can be reduced significantly by mitigation and adaptation actions

Significant reductions in damage costs can be achieved by global and European mitigation policies, consistent with the UNFCCC 2 °C objective, in combination with adaptation actions.

On-going and planned monitoring and research at national and EU level can improve assessments of past and projected impacts of climate change, thereby enhancing the knowledge base for adaptation

Improved information on past and projected climate impacts and on the vulnerability of environmental and social systems is crucial for the planning and implementation of effective adaptation measures. Climate-ADAPT provides a platform for sharing this information with policymakers at the European, national and subnational level.

Longer time series and greater spatial coverage of climate data could be achieved through improved monitoring of Essential Climate Variables from in situ stations and satellites, and reanalysis of European climate data.

The availability of consistent and comparable socio-economic scenarios at the European level could improve integrated climate change vulnerability assessments. The availability of such scenarios, and the use of comparable methods, could also improve the comparability of national impact and vulnerability assessments.

The indicators informing this assessment are based mainly on EU-wide research and on global databases. In the future some indicators on climate impacts and adaptation may be based on data collected from member countries.

Technical summary

Table TS.1 summarises the observed and projected changes for the following indicators:

- changes in the climate system (key climate variables and cryosphere);
- climate impacts on environmental systems (oceans and marine environment, coastal zones, freshwater quantity and quality, terrestrial ecosystems and biodiversity, and soil);
- climate impacts on socio-economic systems and human health (agriculture, forests and forestry, fisheries and aquaculture, human health, energy, transport services and infrastructure, and tourism).

Table TS.1 Observed and projected climate change and impacts on environmental and socio-economic systems and human health

	What is already happening	What could happen
Changes in the climate system		
Key climate variables		
Global temperature (C)	Three independent long records of global average (land and ocean) annual temperature show that the decade between 2002 and 2011 was 0.77 °C to 0.80 °C warmer than the pre-industrial average. The Arctic has warmed significantly more than the globe as a whole.	The further rise in global average temperature is projected to be between 1.1–6.4 °C by 2100 taking climate model uncertainties into account. The EU target of limiting global average temperature increase to 2 °C above pre-industrial levels is projected to be exceeded during the second half of this century and likely around 2050 for scenarios that assume no global mitigation policy. The Arctic is projected to warm more than the globe.
European temperature (C)	The average temperature for the European land area for the last decade (2002–2011) is 1.3 °C above the pre-industrial level, which makes it the warmest decade on record. Heat waves have increased in frequency and length.	Land temperature in Europe is projected to increase between 2.5 °C and 4.0 °C by 2071–2100. The largest temperature increases during the 21st century are projected over eastern and northern Europe in winter and over southern Europe in summer. Heat waves are projected to become more frequent and last longer across Europe over the 21st century.
Precipitation (C)	Precipitation changes across Europe show more spatial and temporal variability than temperature. Since the mid-20th century, annual precipitation has been generally increasing across most of northern Europe, most notably in winter, but decreasing in parts of southern Europe. In Western Europe intense precipitation events have significantly contributed to the increase. There are no widespread significant trends in the number of either consecutive dry or wet days across Europe.	Most climate model projections show continued precipitation increases in northern Europe (most notably during winter) and decreases in southern Europe (most notably during summer). The number of days with high precipitation is projected to increase.
Storms (C)	Observations of storm location, frequency and intensity show considerable variability across Europe during the 20th century. Storm frequency shows a general increasing trend from the 1960s to 1990s, followed by a decrease to the present.	Available climate change projections show no clear consensus in either the direction of movement or the intensity of storm activity.

Table TS.1 Observed and projected climate change and impacts on environmental and socio-economic systems and human health (cont.)

	What is already happening	What could happen
Cryosphere		
Snow cover (C)	Snow cover extent in the Northern Hemisphere has fallen by 7 % in March and 11 % in April during the past four decades. In winter and autumn no significant changes have occurred. Snow mass in Europe has decreased by 7 % in March from 1982 to 2009.	Model simulations project widespread reductions in the extent and duration of snow cover in Europe over the 21st century.
Greenland ice sheet (C)	The Greenland ice sheet changed in the 1990s from being in near mass balance to losing about 100 billion tonnes of ice per year. Ice losses have since then more than doubled to 250 billion tonnes a year averaged over 2005 to 2009. The recent melting of the Greenland Ice Sheet is estimated to have contributed up to 0.7 millimetres a year to global sea-level rise (about one quarter of the total sea-level rise).	Model projections suggest further declines of the Greenland ice sheet in the future but the processes determining the rate of change are still poorly understood.
Glaciers (C)	The vast majority of glaciers in the European glacial regions are in retreat. Glaciers in the European Alps have lost approximately two thirds of their volume since 1850, with clear acceleration since the 1980s.	Glacier retreat is expected to continue in the future. The volume of European glaciers has been estimated to decline between 22 and 66 % compared to the current situation by 2100 under a business-as-usual emission scenario.
Arctic (C) and Baltic sea ice (N)	The extent and volume of Arctic sea ice has declined rapidly since 1980, especially in summer. Record low sea ice cover in September 2007, 2011 and 2012 was roughly half the size of the normal minimum extent in the 1980s.The decline in summer sea ice appears to have accelerated since 1999. The maximum sea ice extent in the Baltic sea has been decreasing since about 1800.	Arctic Sea ice is projected to continue to shrink in extent and thickness and may even disappear completely at the end of the summer melt season in the coming decades. It is expected that there will still be substantial ice in winter. Baltic Sea ice, in particular the extent of the maximal cover, is projected to shrink further.
Permafrost (C)	In the past 10–20 years European permafrost has shown a general warming trend, with greatest warming in Svalbard and Scandinavia. The active layer thickness (i.e. the thawing depth) has increased at some European permafrost sites.	Present and projected atmospheric warming is projected to lead to wide-spread warming and thawing of permafrost.
Climate impacts on environmental systems		
Oceans and marine environment		
Ocean acidification (N)	Surface-ocean pH has declined from 8.2 to 8.1 over the industrial era due to the growth of atmospheric CO_2 concentrations. This decline corresponds to a 30 % increase in oceanic acidity. Observed reductions in surface-water pH are nearly identical across the global ocean and throughout Europe's seas. Ocean acidification in recent decades is occurring a hundred times faster than during past natural events over the last 55 million years. Ocean acidification already reaches into the deep ocean, particularly in the high latitudes.	Average surface-water pH is projected to decline further to 7.7 or 7.8 by the year 2100, depending on future CO_2 emissions. This decline represents a 100 to 150 % increase in acidity relative to present conditions. Ocean acidification may affect many marine organisms within the next 20 years and could alter marine ecosystems and fisheries.
Ocean heat content (N)	Heat increases in the world's oceans accounts for approximately 93 % of the warming of the earth system during the last six decades. An increasing trend in the heat content in the uppermost 700 m of the world's oceans is evident over the last six decades. Recent observations show substantial warming of the deeper ocean (between 700 and 2 000 m depth).	Further warming of the oceans is expected with projected climate change, but quantitative projections of ocean heat content are not available.
Sea surface temperature (C)	Sea surface temperature in European seas is increasing more rapidly than in the global oceans. The rate of increase in sea surface temperature in all European seas during the past 25 years is the largest ever measured in any previous 25-year period.	Global sea surface temperature is projected to rise more slowly than atmospheric temperature.
Phenology of marine species (C)	Many marine organisms in European seas appear earlier in their seasonal cycles than in the past. Some plankton species have advanced their seasonal cycle by four to six weeks in recent decades.	Projections of the phenological responses of individual species are not available, but phenological changes are expected to continue with projected further climate change.

Table TS.1 Observed and projected climate change and impacts on environmental and socio-economic systems and human health (cont.)

	What is already happening	What could happen
Distribution of marine species (C)	A major northward expansion of warmer-water plankton in the north-east Atlantic and a northward retreat of colder-water plankton has taken place. The northerly movement is about 10 ° latitude (1 100 km) over the past 40 years, and it seems to have accelerated since 2000. Sub-tropical species are occurring with increasing frequency in European waters and sub-Arctic species are receding northwards.	Further changes in the distribution of marine species are expected, with projected further climate change, but quantitative projections are not available.
Coastal zones		
Global and European sea-level rise (C)	Tide gauges show a global mean sea-level rise of around 1.7 mm/year over the 20th century. Satellite measurements show a rise of around 3 mm/year over the last two decades. Sea level is not rising uniformly at all locations, with some locations experiencing much greater than average rise. Coastal impacts also depend on the vertical movement of the land, which can either add to or subtract from climate-induced sea-level change, depending on the location.	Projections of global mean sea-level rise in the 21st century range between 20 cm and about 2 m by the end of the century. Modelling uncertainty contributes at least as much to the overall uncertainty as uncertainty about future greenhouse gas emission scenarios. It is likely that 21st century sea-level rise will be greater than during the 20th century. Current projections suggest that it is more likely to be less than 1 m than to be more than 1 m.
Storm surges (N)	Several large storm surge events have caused loss of life and damage to property in Europe during the past century. Extreme coastal water levels have increased at many locations around the European coastline, mainly due to increases in mean local sea level rather than to changes in storm activity. Large natural variability and lack of good quality long observational records makes detecting long-term changes in trends in extreme coastal sea levels difficult.	Projections of changes in storms and storm surges for the European region have a high uncertainty. Increases in extreme coastal water levels will likely be dominated by increases in local relative mean sea level, with changes in the surge component being less important at most locations.
Coastal erosion (C)	About one quarter of the European coastline for which data is available is currently eroding, due partly to increasing human activities in the coastal zone.	Projections for coastal erosion are not available. Future climate change, in particular rising sea levels, is expected to accelerate coastal erosion.
Freshwater quantity and quality		
River flow (C)	Climate change induced long-term trends in river flows are difficult to detect due to substantial natural variability and modifications from water abstractions, man-made reservoirs and land-use changes. Nevertheless, increased river flows during winter and lower river flows during summer have been recorded since the 1960s in large parts of Europe.	Climate change is projected to result in strong changes in the seasonality of river flows across Europe. Summer flows are projected to decrease in most of Europe, including in regions where annual flows are projected to increase.
River floods (C)	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.	Global warming is projected to intensify the hydrological cycle and increase the occurrence and frequency of flood events in large parts of Europe. Pluvial floods and in particular flash floods, which are triggered by local intense precipitation events, are also likely to become more frequent throughout Europe. In regions with projected reduced snow accumulation during winter (e.g. north-eastern Europe), the risk of early spring flooding could decrease. However quantitative projections for flood frequency and intensity are uncertain.
River flow drought (C)	Europe has been affected by several major droughts in recent decades, 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.	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.
Water temperature (C)	Water temperature in major European rivers and lakes has increased by 1–3 °C over the last century.	Lake and river surface water temperatures are projected to increase with further increases in air temperature.
Lake and river ice cover (C)	The duration of ice cover on European lakes and rivers has shortened at a mean rate of 12 days per century over the last 150–200 years.	A further decrease in the duration of lake ice cover is projected.

Table TS.1 Observed and projected climate change and impacts on environmental and socio-economic systems and human health (cont.)

	What is already happening	What could happen
Freshwater ecosystems and water quality (C)	Cold-water species have been observed to move northwards or to higher altitudes. Changes in life cycle events (phenology) have been observed. Phytoplankton and zooplankton blooms in several European lakes are now occurring one month earlier than 30–40 years ago. Biological invasions of species (including toxic species) that originate in warmer regions have been observed.	The observed changes are projected to continue with further projected climate change. Increases in nutrient and dissolved organic carbon concentrations in lakes and rivers may occur, but management changes can have much larger effects than climate change.
Terrestrial ecosystems and biodiversity		
Plant and fungi phenology (C)	The timing of seasonal events in plants is changing. 78 % of leaf unfolding and flowering records show advancing trends in recent decades whereas only 3 % show a significant delay. Between 1971 and 2000, the average advance of spring and summer was between 2.5 and 4 days per decade. The pollen season starts on average 10 days earlier and is longer than 50 years ago.	Trends in seasonal events are projected to advance further as climate change proceeds.
Animal phenology (C)	Many animal groups have advanced their life cycles in recent decades, including frogs spawning, birds nesting and the arrival of migrant birds and butterflies. The breeding season of many thermophilic insects (such as butterflies, dragonflies and bark beetles) has been lengthening, allowing more generations to be produced per year.	The observed trends are expected to continue in the future but quantitative projections are rather uncertain.
Distribution of plant species (C)	Several European plant species have shifted their distribution northward and uphill. Mountain ecosystems in many parts of Europe are changing as plant species expand uphill.	Cold-adapted species are projected to lose climatically suitable areas in mountains. By the late 21st century, European plant species are projected to shift several hundred kilometres to the north, forests are likely to contract in the south and expand in the north, and about half of the mountain plant species may face extinction. The rate of climate change is expected to exceed the ability of many plant species to migrate, especially as landscape fragmentation may restrict movement.
Distribution and abundance of animal species (C)	There is a clear poleward trend of butterfly distributions from 1990 to 2007 in Europe. Nevertheless, the migration of many species is lagging behind the changes in climate, suggesting that they are unable to keep pace with the speed of climate change.	Distribution changes are projected to continue. Suitable climatic conditions for Europe's breeding birds are projected to shift nearly 550 km northeast by the end of the 21st century under a scenario of 3 °C warming, with the average range size shrinking by 20 %. Habitat use, fragmentation and other obstacles are impeding the migration of many animal species. The difference between required and actual migration rate may lead to a progressive decline in European biodiversity.
Soil		
Soil organic carbon (C)	On average, soils in Europe are most likely accumulating carbon. Soils under grassland and forest are a carbon sink, whereas soils under arable land are a smaller carbon source.	Climate change is expected to have an impact on soil carbon in the long term, but changes in the short term will more likely be driven by land management practices and land use change.
Soil erosion (C)	About 130 million ha of land in the EU is affected by soil erosion by water, of which almost 20 % shows soil loss in excess of 10 t/ha/year. 42 million ha of land is affected by wind erosion, of which around 1 million ha is severely affected.	Increased variations in rainfall pattern and intensity are expected to make soils more susceptible to water erosion and increased aridity would make finer-textured soils more vulnerable to wind erosion. However reliable quantitative projections are not available.
Soil moisture (C)	There is no clear indication on past trends for water retention across the EU due to a lack of systematic and harmonised data.	Projections suggest a reduction in summer soil moisture over most of Europe, significant reductions in the Mediterranean region, and increases in the northeastern part of Europe.

Table TS.1 Observed and projected climate change and impacts on environmental and socio-economic systems and human health (cont.)

	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 a 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.
Forests and forestry		
Forest growth (C)	Forest biomass and the area covered by forests and other wooded land have increased over the past decades. In some central and western forest areas of Europe, forest growth has been reduced in the last 10 years due to storms, pests and diseases.	Forest growth is projected to increase in northern Europe and to decrease in southern Europe under projected future climate change.
Forest fires (C)	The number of fires in the Mediterranean region has increased over the period from 1980 to 2000 and decreased thereafter. The impact of fire events is particularly strong on already degraded ecosystems in southern Europe.	In a warmer climate, more severe fire weather and, as a consequence, an expansion of the fire-prone area and longer fire seasons are projected, but with considerable regional variation.
Fisheries and aquaculture (N)	Wild fish stocks seem to be responding to changing temperatures and food supply by changing their geographical distribution.	Future projected climate change is likely to lead to an increased catch potential in the Arctic, and to a decreased or constant catch potential in other European seas. Climate change can influence where aquaculture is possible, which species are raised, and the efficiency of the production.
Human health		
Floods and health (N)	River and coastal flooding affect millions of people in Europe each year. Effects include drowning, heart attacks, injuries, infections, psychosocial consequences, health effects of chemical hazards, and disruption of services.	Increases in health risks associated with river and coastal flooding are projected in many regions of Europe due to projected increases in extreme precipitation events and sea level.
Extreme temperatures and health (C)	Mortality and morbidity increase, especially in vulnerable population groups, and general population well-being decreases during extreme cold spells and heat-waves, as well as above and below local and seasonal comfort temperatures, with different temperature thresholds in Europe. Heat-waves over the last decade have caused tens of thousands of premature deaths in Europe.	Length, frequency, and intensity of heat-waves are very likely to increase in the future. This increase can lead to a substantial increase in mortality over the next decades, especially in vulnerable groups, unless adaptation measures are taken. Cold-related mortality is projected to decrease in many countries due to climate change as well as better social, economic, and housing conditions.
Air pollution by ozone and health (C)	Excessive exposure to ground-level ozone is estimated to cause about 20 000 premature deaths per year in Europe. Attribution of observed changes in ozone exceedances to climate change is difficult.	Future projected climate change is expected to increase ozone concentrations but this effect will most likely be outweighed by reduction in ozone levels due to expected future emission reductions.

Table TS.1 Observed and projected climate change and impacts on environmental and socio-economic systems and human health (cont.)

	What is already happening	What could happen
Vector-borne diseases (C)	The transmission cycles of vector-borne diseases are sensitive to climatic factors but also to land use, vector control, human behaviour, and public health capacities. Climate change is the main factor behind the observed northward and upward move of the tick species *Ixodes ricinus* in parts of Europe.	Climate change is projected to lead to further northward and upward shifts in the distribution of *Ixodes ricinus*. It is also expected to affect the habitat suitability for a wide range of disease vectors, including Aedes albopictus and the phlebotomine species of sandflies.
Water- and foodborne diseases (C)	It is not possible to assess whether climate change has already affected water- and food-borne diseases in Europe.	Climate change is projected to increase the risk of food- and water-borne diseases in many parts of Europe. Projected increased temperatures could increase the risk of salmonellosis. Where precipitation or extreme flooding is projected to increase in Europe, the risk of campylobacteriosis and cryptosporidiosis could increase.
Energy		
(N)	The number of heating degree days has decreased by an average of 16 per year since 1980. This decrease helps reduce the demand for heating, particularly in northern and north-western Europe. Cooling degree days are increasing but time series are not available.	Climate change is projected to reduce demand for heating in northern and north-western Europe and to strongly increase energy demand for cooling in southern Europe, which may further exacerbate peaks in electricity supply in the summer. Further increases in temperature and droughts may limit the availability of cooling water for thermal power generation in summer.
Transport		
(N)	Land-based and water-based transport infrastructure and operation is sensitive to changes in climate. Data on past climate-related impacts on transport are restricted to individual extreme events, and attribution to climate change is generally not possible.	Climate change is projected to have both beneficial and adverse impacts on transport, depending on the region and the transport mode. Rail transport is projected to face the highest percentage increase in costs from extreme weather events. The British Isles, central Europe, eastern Europe, France and Scandinavia are projected to be most adversely impacted.
Tourism		
(C)	Climatic suitability for general tourism activities is currently best in southern Europe.	Touristic attractiveness in northern and Central Europe is projected to increase in most seasons. The suitability of southern Europe for tourism is projected to decline markedly during the key summer months but improve in other seasons. Projected reductions in snow cover will negatively affect the winter sports industry in many regions, in particular regions close to the low elevation limit for winter sport. Economic consequences for regions where tourism is an important economic sector can be substantial, but this is strongly determined by non-climatic factors, such as the ability of tourists to adjust the timing of their holidays.

Note: Letters in brackets compare information in the 2012 report with the 2008 report: (C) = broadly consistent; (N) = new information.

Regional impacts and vulnerability

Overview

Human systems and ecosystems in Europe are vulnerable to major climate change impacts such as river floods, droughts or coastal flooding. In various regions, a combination of different types of these impacts can exacerbate vulnerabilities. Vulnerabilities differ across Europe depending on local conditions.

A summary of regional impacts and vulnerabilities is presented (see also Map TS.1 and Table TS.2).

Socio-economic developments (e.g. population and wealth growth leading to increasing exposed systems such as houses and other infrastructures) are a key driver (in addition to climate change) of projected increases in climate change impacts. There are significant differences in adaptive capacity across Europe. When major climate change impacts affect regions with a low adaptive capacity, the consequences are severe. An integrated assessment of European regions' vulnerability to climate change suggests that climate change could deepen existing socio-economic imbalances in Europe and may negatively affect the territorial cohesion.

The Arctic

The Arctic faces major changes including a higher than average temperature increase, a decrease in summer sea ice cover and thawing of permafrost. The reduction of ice cover is accelerating and projected to continue to impact the local natural and human systems. It also opens up business opportunities that could put an additional burden on the environment such as extensive oil and gas exploration and the opening of new shipping routes. Thawing of permafrost has the potential to seriously affect human systems, by, for example, creating infrastructural problems. The fragile Arctic ecosystems have suffered significantly from above average temperature increases and these impacts are expected to continue.

Northern Europe

Projections suggest less snow and lake and river ice cover, increased winter and spring river flows in some parts (e.g. Norway) and decreases in other parts (e.g. Finland), and greater damage by winter storms. Climate change could offer opportunities in northern Europe, at least in the short and medium terms. These include increased crop variety and yields, enhanced forests 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 in the medium to long term might adversely impact the region, for example by making crop yields more variable.

North-western Europe

Coastal flooding has impacted low-lying coastal areas in north-western Europe in the past and the risks are expected to increase due to sea-level rise and an increased risk of storm surges. North Sea countries are particularly vulnerable, especially Belgium, Denmark, Germany, the Netherlands and the United Kingdom. Higher winter precipitation is projected to increase the intensity and frequency of winter and spring river flooding, although to date no increased trends in flooding have been observed.

Central and eastern Europe

Temperature extremes are projected to be a key impact in central and eastern Europe. Together with reduced summer precipitation this can increase the risk of droughts, and is projected to increase energy demand in summer. The intensity and frequency of river floods in winter and spring (in various regions) is projected to increase due to increases in winter precipitation. Climate change is also projected to lead to higher crop-yield variability and increased occurrence of forest fires.

Mediterranean region

The Mediterranean region has been subject to major impacts over recent decades as a result of decreased precipitation and increased temperature, and these are expected to worsen as the climate continues to change. The main impacts are decreases in water availability and crop yields, increasing risks of droughts and biodiversity loss, forest fires and heat waves. Increasing irrigation efficiency in agriculture can reduce irrigation water withdrawals to some degree but will not be sufficient to compensate for climate-induced increases in water stress. In addition the hydropower sector will be increasingly affected by lower water availability and increasing energy demand, while the tourism industry will face less favourable conditions in summer. Environmental flows, which are important for the healthy maintenance of aquatic ecosystems, are threatened by climate change impacts and socio-economic developments.

Cities and urban areas

In previous years, increasing urban land take and urban population growth have in many places increased the exposure of European cities to different climate impacts such as heat waves, flooding and droughts. The impacts of extreme events such as the flooding of the river Elbe (2002) or the urban drainage flood in Copenhagen (2011) demonstrate the high vulnerability of cities to extreme weather events, even though it is not possible to attribute these specific events to anthropogenic climate change. In the future, on-going urban land take, growth and concentration of population in cities, and an aging population, contribute to increase further the vulnerability of cities to climate change. Urban design, urban management and enhancing green infrastructure may partly address these effects.

Mountain areas

The increase in temperature is particularly high in many mountain regions, where loss of glacier mass, reduced snow cover, thawing of permafrost and changing precipitation patterns, including less precipitation falling as snow, have been observed and are expected to increase further. This could lead to an increase in the frequency and intensity of floods in some mountain areas (e.g. in parts of Scandinavia) that can impact people and the built environment. Additional projected impacts include reduced winter tourism, lower energy potential from hydropower in southern Europe, a shift in vegetation zones and extensive biodiversity loss. Plant and animal species living close to mountain tops face the risk of becoming extinct due to the inability to migrate to higher regions.

The retreat of the vast majority of glaciers also affects water availability in downstream areas.

Damage costs

Damage costs from weather and climate-related disasters

Hydro-meteorological events (storms, floods, and landslides) account for 64 % of the reported damage costs due to natural disasters in Europe since 1980; climatological events (extreme temperatures; droughts and forest fires) account for another 20 %. It is, however, difficult to determine accurately the proportion of damages that are attributable to climate change. Damages from extreme weather events have increased from EUR 9 billion in the 1980s to more than EUR 13 billion in the 2000s. The increased in damages is primarily due to increases in population, economic wealth and human activities in hazard-prone areas and to better reporting. The contribution of climate change to the damage costs from natural disasters is expected to increase due to the projected changes in the intensity and frequency of extreme weather events.

Projected costs of climate change impacts

Projections suggest potentially large costs of combined climate change impacts and socio-economic developments in Europe, particularly due to increases in coastal and river flooding, heat waves and energy demand (for cooling). The most costly impacts differ strongly across Europe. In southern parts of Europe the most costly impacts are increases in energy demand and heat waves, in western Europe coastal flooding and heat waves, in northern Europe coastal and river floods and in eastern Europe river floods. Significant reductions in costs can be achieved by global and European mitigation policies, consistent with the UNFCCC 2 °C objective, in combination with adaptation actions.

Cost estimates have a medium to good coverage at European level for coastal and river flooding, water supply, energy demand, agriculture and human health, but for various key sectors cost estimates are fragmentary or unavailable (infrastructure, built environment, tourism, transport, forestry). For biodiversity and ecosystem services cost estimates are difficult to prepare due to the challenge of proper valuation. Estimates of the total costs of future climate change on the European economy are currently not available.

Data availability and needs

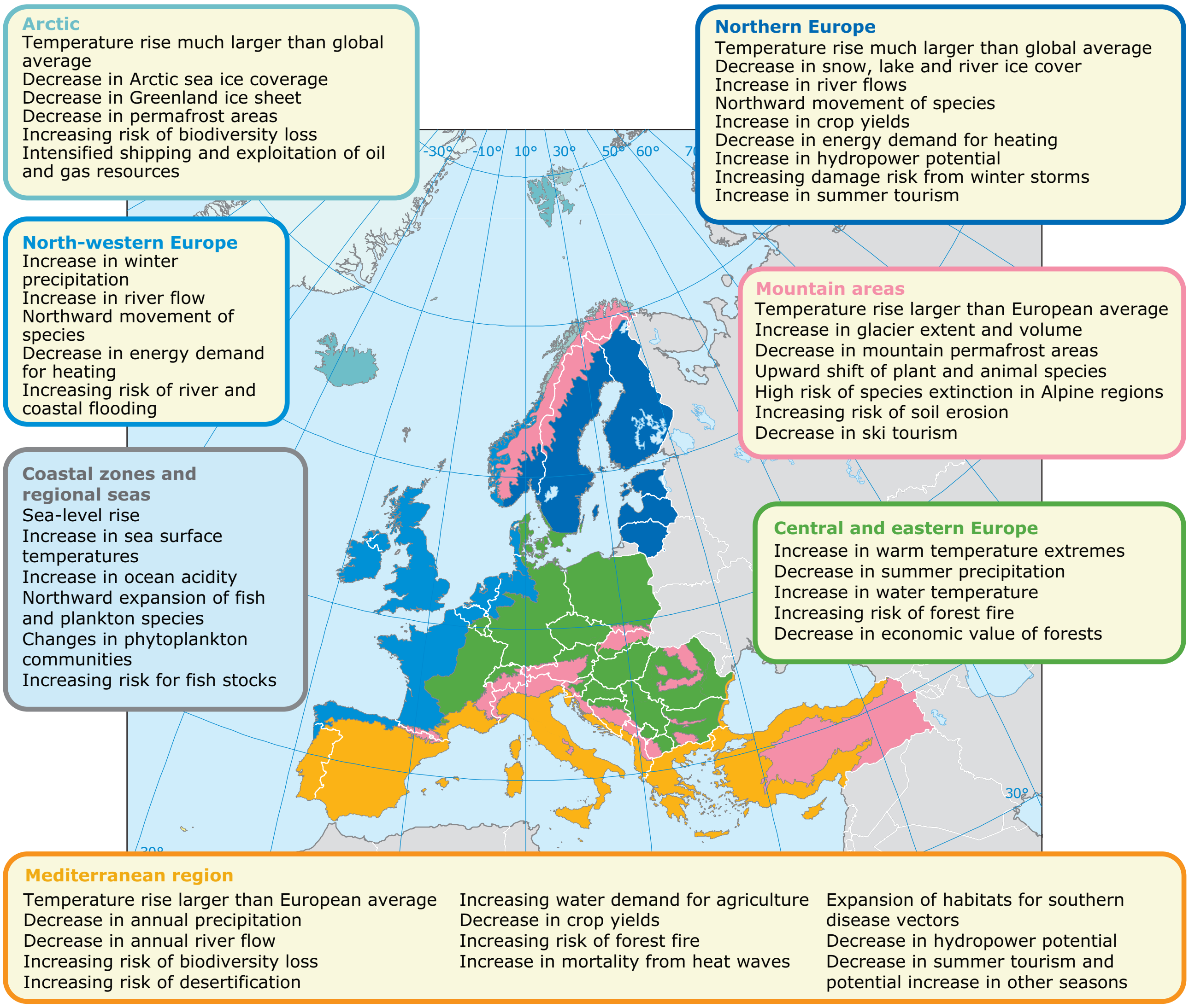
The available data and indicators show that climate change is occurring and causes a multitude of different impacts. Longer time series and greater spatial coverage of both climate change and its impacts can provide greater insights into processes of change and a more diversified picture across Europe. Actions being undertaken globally and in Europe to improve monitoring of Essential Climate Variables (ECVs) from both in situ stations and using satellites are expected to enhance the knowledge base. In addition on-going and planned actions on reanalysis of European climate data will improve the understanding of climate change. It is important that the planned actions are implemented. Currently there is a lack of sufficient observations of impacts of climate change on various environmental and socio-economic systems and on human health. Properly including climate change impact aspects in existing monitoring systems can improve the knowledge base needed to develop evidence based adaptation policies and actions.

European wide integrated climate change vulnerability assessments apply different methodologies, and the underlying datasets have important limitations. The availability of consistent and comparable information at EU level on scenarios for key socio-economic and physical variables is incomplete. Also European wide projections of cost estimates of impacts, including damages of extreme weather events, can be improved. On-going and planned EU funded research is expected to improve this situation.

Many European countries have performed national and sub-national climate change vulnerability and risk assessments while several countries have not yet done so. The comparability of national assessments, including the national impact indicators, may be improved in future for example by using comparable methods and climate and socio-economic projections.

Climate change impacts indicators are currently only to a very limited extent included within existing and emerging European thematic and sectoral indicator sets, but this should be considered in future improvements of these indicator sets. The indicators informing this assessment are based on EU-wide research and on global databases. Some selected indicators may in the future be based on data collected from member countries, e.g. through the European Climate Adaptation Platform Climate-ADAPT (http://climate-adapt.eea.europa.eu) and/or through reporting of indicators by Member States to the European Commission and the EEA.

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



Note: Information covers both observed and projected changes (see text and Table TS.2 for details).

Table TS.2 Key observed (O) and projected (P) climate change and impacts for the main regions in Europe

			Northern Europe (incl. Arctic)		North-western Europe		Central and eastern Europe		Medi-terranean region		European average	
Section	**Indicator/topic**	**Variable**	**O**	**P**	**O**	**P**	**O**	**P**	**O**	**P**	**O**	**P**
2	**Changes in the climate system**											
2.2	**Key climate variables**											
2.2.2	Global and European Temperature	Temperature	+	+	+	+	+	+	+	+		
2.2.3	Temperature extremes (Warm)	Frequency	+	+	+	+	+	+	+	+		
2.2.3	Temperature extremes (Cold)	Frequency	–	–	–	–	–	–	–	–		
2.2.4	Mean precipitation	Precipitation	+	+	+	(+)	o	(+)	–	–		
2.2.5	Precipitation extremes (Wet)	Duration/Amount	(+)	+	(+)	+	o	+	(–)	+		
2.2.5	Precipitation extremes (Dry)	Duration	±		(+)		o		(+)			
2.2.6	Storms	Wind speed	+	(+)	+	(+)	(+)	(+)	o	(–)		
2.3	**Cryosphere**											
2.3.2	Snow cover	Duration/amount	±	±	–	–	(–)	(–)	(–)	–		
2.3.3	Greenland ice sheet	Mass	–	–								
2.3.4	Glaciers	Mass	±	(–)			–	–	–	–		
2.3.5	Permafrost	Active layer depth	+	+			+		+			
2.3.6	Arctic and Baltic sea ice	*See below*										
3	**Climate impacts on environmental systems**											
3.1	**Oceans and marine environment**	*See below*										
3.2	**Coastal zones**											
3.2.2	Sea-level rise	Mean sea level (excl. land movement)	+	+	+	+	+	+	(+)	(+)		
3.2.3	Storm surges	Surge height (in addition to mean sea level)	(+)	(+)	o	(+)	o	(+)	o	–		
3.3	**Inland waters**											
3.3.2	River flow	Mean flow	+	+	(+)	+	±	±	–	–		
3.3.3	River floods	Maximum flow		±	+	+		±		±		
3.3.4	River flow drought	Minimum flow	o	+	o	–	o	±	o	–		
3.3.5	Water temperature	Temperature	+	+	+	+	+	+	+	+		
3.3.6	Lake and river ice cover	Duration	–	–	–	–	–	–	–	–		
3.4	**Terrestrial ecosystems and biodiversity**											
3.4.2	Plant and fungi phenology	Day of year (spring/summer)									–	–
3.4.3	Animal phenology	Day of year (spring/summer)									–	–
3.4.4	Distribution of plant species	Latitude and altitude									+	+
3.4.5	Distribution and abundance of animal species	Latitude and altitude									+	+
3.5	**Soil**											
3.5.2	Soil organic carbon	Carbon content									+	
4	**Climate impacts on socio-economic systems and health**											
4.1	**Agriculture**											
4.1.2	Growing season for agricultural crops	Duration	(+)		+		(+)		(+)			+
4.1.3	Agrophenology	Day of year	–	–	–	–	–	–	–	–		
4.1.4	Water-limited crop productivity	Yield	+	+	±	±		±	–	(–)		
4.1.5	Irrigation water requirement	Water requirement	(–)		o		(+)		±	(+)		

Table TS.2 Key observed (O) and projected (P) climate change and impacts for the main regions in Europe (cont.)

Section	Indicator/topic	Variable	Northern Europe (incl. Arctic) O	Northern Europe (incl. Arctic) P	North-western Europe O	North-western Europe P	Central and eastern Europe O	Central and eastern Europe P	Medi-terranean region O	Medi-terranean region P	European average O	European average P
4.2	**Forests and forestry**											
4.2.2	Forest growth	Biomass		+		+		±		(−)	+	
4.2.3	Forest fires	Area							(+)			+
4.3	**Fisheries and aquaculture**	*See below*										
4.4	**Human health**											
4.4.3	Floods and health	People flooded				+						+
4.4.4	Extreme temperatures and health	Mortality								+		+
4.4.5	Air pollution by ozone and health	Ozone levels	(+)	−	o		(+)		(+)	+		
4.4.6	Vector-borne diseases	People infected										(+)
4.5	**Energy**											
4.5.2	Heating degree days	Heating demand	−	−	−	−	−	−	(−)	(−)		
4.5.3	Electricity demand	Electricity demand		−						+		
4.5.3	Electricity production	Electricity production		+		−		−		−		
4.6	**Transport**											
4.6.3	Impacts of changes in weather extremes	Costs					+					±
4.7	**Tourism**											
4.7.2	General tourism	Attractivity		+		+		±		(−)		
4.7.3	Winter sport tourism	Attractivity		(−)				(−)				
5	**Vulnerability to climate change**											
5.5	**Damage costs related to climate change**											
5.5.1	Damages from weather and climate-related events	Damage costs									+	+
5.5.2	Projected costs of climate change	Costs										+
			Arctic ocean		**Atlantic and North Sea**		**Baltic Sea**		**Medi-terranean Sea**		**All European seas**	
2.3.6	Arctic and Baltic sea ice	Duration/extent	−	−			−	−				
3.1	**Oceans and marine environment**											
3.1.2	Ocean acidification	Acidity									+	+
3.1.3	Ocean heat content	Heat content									+	+
3.1.4	Sea surface temperature	Temperature									+	+
3.1.5	Phenology of marine species	Day of year			+							
3.1.6	Distribution of marine species	Latitude			+							
4.3	**Fisheries and aquaculture**	Catch potential		+								

Legend: +: Increase in variable throughout (most of the) region

−: Decrease in variable throughout (most of the) region

±: Increases as well as decreases in the variable in the region

o: Only small changes in variable

(): Increase or decrease only in some parts of the region

Green: Beneficial change

Red: Adverse change

Note: Information refers to different time horizons, emissions scenarios and socio-economic scenarios. Some observations and projections have lower levels of confidence than others.

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