THE EUROPEAN ENVIRONMENT

STATE AND OUTLOOK 2010

ADAPTING TO CLIMATE CHANGE

European Environment Agency

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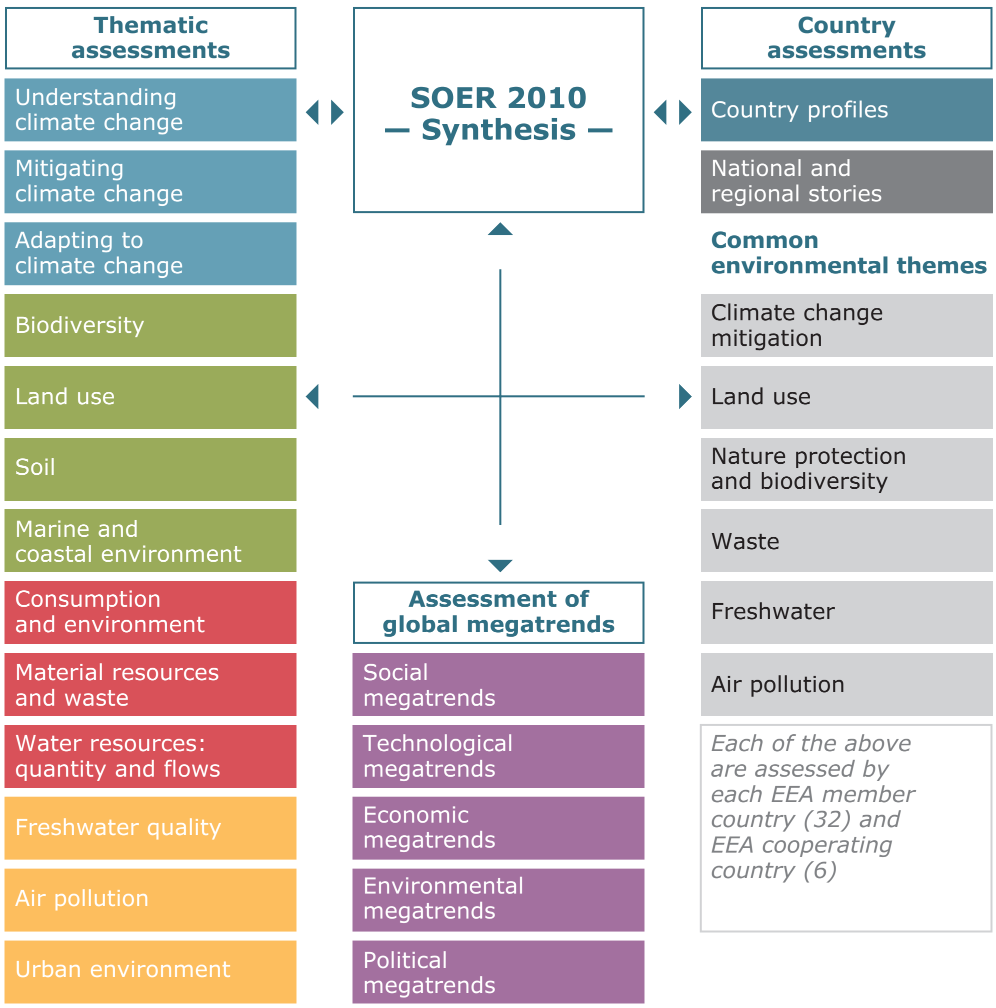
3. a set of 38 **country assessments** of the environment in individual European countries;
4. a **synthesis** — an integrated assessment based on the above assessments and other EEA activities.

SOER 2010 assessments



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Adapting to climate change

Summary

Climate change is happening and will continue to have far-reaching consequences for human and natural systems. Impacts and vulnerabilities differ considerably across regions, territories and economic sectors in Europe. Strategies to adapt to climate change are necessary to manage impacts even if global temperature stays below a 2 °C increase above the pre-industrial level. The EU adaptation framework aims at developing a comprehensive strategy by 2013, to be supported by a clearinghouse for sharing and maintaining information on climate change impacts, vulnerability and adaptation.

Why do we need to adapt to climate change?

Some climate change is inevitable because of past greenhouse gas emissions. The current global average temperature is about 0.7–0.8 °C above the pre-industrial level. Even if greenhouse gas concentrations had been stabilised in the year 2000, temperature would still increase by 1.2 °C above the pre-industrial level by the end of the 21st century. Strategies to adapt to climate change are therefore necessary. Temperature rises of 2 °C or more above the pre-industrial level are likely to cause major disruptions. They would challenge our ability to adapt at affordable economic, social and environmental cost.

What are the impacts of climate change and the vulnerabilities of Europe?

The vulnerability to climate change varies significantly across regions and sectors in Europe, making adaptation a context- and location-specific challenge. Vulnerable regions include the Mediterranean basin, north-western and central-eastern Europe and the Arctic, together with many coastal zones and other areas prone to river floods, mountains and cities. The costs of adaptation in Europe could potentially be large (possibly billions of euro per year in the medium- and long-term). Available assessments suggest that timely and proportionate adaptation makes economic, social and environmental sense, and is likely to be far less costly than inaction. The majority of projected impacts and vulnerabilities are, or are expected to be, negative, and these often need to be addressed proactively by public policies. The EEA therefore focuses on adverse effects. Impacts and vulnerabilities were identified for various regions.

- Low-lying coastal areas across Europe could face major impacts due to sea level rise and a possible increased frequency of severe storm surges, particularly in north-western Europe. More and more intense winter and spring river floods are expected in this region.
- A northward movement of species is expected due to higher sea surface temperatures.
- Temperature increase is particularly high in mountain areas. Decrease of glacier mass, reduced snow cover, thawing of permafrost and changing precipitation patterns are expected to continue further. Plant and animal species face the risk of extinction due to barriers prohibiting them from moving upwards or northwards to more suitable habitats.
- Cities and urban areas continue to be vulnerable to heat waves, flooding and droughts. These may have knock-on effects on infrastructure, public health and the economy.
- The Mediterranean basin experienced decreased precipitation and increased temperature over past decades, and this trend is projected to worsen. Water availability and crop yields could decrease while droughts, biodiversity loss, forest fires and heat waves may increase.
- The Arctic faces an accelerating decrease in summer sea ice cover. This trend is expected to continue. New business opportunities, such as enhanced oil and gas exploration, could cause additional environmental burdens.
- Temperature extremes are projected to be a key impact in central and eastern Europe. In summer,

reduced precipitation, an increased risk of droughts, and increasing energy demand are also anticipated. In winter and spring, the intensity and frequency of river floods may increase.
- Less snow and lake and river ice cover are projected for northern Europe. At the same time, increased winter and spring river flows and greater damage by winter storms are expected. Climate change may offer certain short- and medium-term opportunities in this region, such as increased forest growth.

What is and can be done in support of successful adaptation policies and measures?

Effective adaptation needs to contemplate all possible climate conditions during the horizon of a policy decision. It should therefore consider no-regret measures (suitable under every plausible scenario) and a broad variety of adaptation options (i.e. grey or technological measures; green/ecosystem-based measures; and soft measures addressing behaviour, management and policies). Adaptation success factors and barriers (typically limited scientific knowledge and uncertainty) are being increasingly identified. Guidance for good practices and the development of adaptation indicators should be further advanced, and this could be usefully informed by regional assessments and case studies.

At a national level, European countries are often aware of the need to adapt to climate change. So far, 11 European countries, and a few regions and cities, have adopted adaptation strategies. The EEA keeps an overview of national adaptation strategies in its 32 member countries (www.eea.europa.eu/themes/climate/national-adaptation-strategies), and helps to transfer lessons learnt.

The EU plans to develop a European Clearinghouse on climate change impacts, vulnerability and adaptation, to address the current lack of knowledge-sharing. Moreover, the European Commission adopted a White Paper on Adaptation to Climate Change in 2009 and plans to publish a Communication on Mainstreaming Adaptation and Mitigation in 2011. A comprehensive EU adaptation strategy is expected to be developed by 2013. Internationally, the EU supports particularly vulnerable developing countries under the umbrella of the United Nations Framework Convention for Climate Change (UNFCCC).

1 Overview

This assessment addresses climate change vulnerabilities and adaptation ([1]). Global climate observations, science and physical impacts as well as mitigation — the reduction of greenhouse gas (GHG) emissions — are covered in separate analyses ([2]).

To achieve the EU's objective of limiting the global temperature increase to 2 °C above pre-industrial levels, global GHG emissions need to stop increasing in the coming decade and be reduced significantly thereafter. However, some climate change is inevitable due to past emissions. To complement mitigation efforts, we must, therefore, also develop strategies and actions to adapt to the impacts of climate change. The EU also recognises that developing countries are among the most vulnerable due to limited financial and technical capacity, and is committed to contributing its fair share in supporting developing countries cope with and adapt to climate change.

This assessment focuses primarily on the adverse effects of climate change and does not discuss extensively possible opportunities. This risk-oriented approach is based on the understanding that the majority of the projected impacts of climate change in Europe will be negative (IPCC, 2007). Furthermore, adverse impacts of climate change are more important for policymaking since many of them need to be addressed proactively by public policies whereas beneficial impacts can often be exploited by autonomous adaptation of private actors.

1.1 Key challenges for European society

Climate change has far-reaching consequences and is one of the key drivers of global environmental change. Current and projected impacts in Europe, together with their related costs, suggest that climate change will — either directly or indirectly — test the vulnerability of European society with economic, environmental, societal, geopolitical and technological risks ([3]). The security, health and quality of life of European citizens are at the core of the matter and climate change constitutes an additional pressure ([4]) that challenges most of the components of human and natural systems.

Europe faces significant challenges from current and expected climate change, ranging from gradual ones — increase in temperature, loss of biodiversity, and rise of sea level — to sudden and extreme events — storms and flooding. Human systems in Europe are expected to be heavily affected by health problems and fatalities as a result of heat waves, floods, etc.; unbearable costs of damage to communities, infrastructures and the built environment from, for example, droughts and water scarcity; the loss of economic opportunities from, *inter alia*, lower crop yields and changing patterns of tourism; and a loss in the quality of life as a result, for example, of stress. Climate change will directly or indirectly affect all economic sectors, regions and citizens, although to different degrees depending on their coping and adaptive capacities as well as their location. The consequences of climate change will also have feedback effects on socio-economic developments, such as settlement patterns especially in regions and areas that are particularly vulnerable, such as coastal zones, flood plains, mountains and cities as well as the Mediterranean basin and the Arctic.

Drivers of socio-economic development in Europe also have the potential to exacerbate the impacts of climate change. For example land-cover and land-use changes such as urban sprawl and soil sealing may heighten the effects of floods, heat island effects and heat waves on urban systems or food systems could be impacted by water scarcity.

Natural systems provide vital ecosystem goods and services for many human activities including agriculture, forestry, fisheries, tourism and the supply of clean water.

([1]) See also the other SOER 2010 biodiversity assessment (EEA, 2010c), land use assessment (EEA, 2010d), marine and coastal environment assessment (EEA, 2010e), water resources: quantity and flows assessment (EEA, 2010f), freshwater quality assessment (EEA, 2010g) and urban environment assessment (EEA, 2010h).
([2]) See EEA, 2010i and EEA, 2010j.
([3]) Economic risks: volatility in food and raw material prices; under-investment in infrastructure; economic downturn. Environmental risks: droughts and desertification, extreme whether, water scarcity. Societal risks: diseases, pandemics, migration. Geopolitical risks: terrorism, corruption, governance gaps. Technological risks: information gaps (WEF, 2010).
([4]) Together with equally important issues such as freshwater extraction, urban sprawl, lifestyles and other forms of socio-economic development and land-use changes, agricultural intensification, use of natural capital and loss of biodiversity.

The impacts of climate change on natural systems are expected to be far-reaching — for example, the loss of biodiversity in terms of species and habitats — and may have knock-on effects on human systems such as lowering economic output or the quality of life.

The magnitude of climate change impacts on human and natural systems in Europe calls for vigorous adaptation responses that both reduce the vulnerability of these systems — downstream adaptation such as technological solutions — and further strengthen their resilience — upstream adaptation, for example, ecosystem-based and managerial options. The latter will specifically reinforce key components of coping and adaptive capacities in terms of socio-economic, institutional and governance structures and the natural capital. Two key policy levers for advancing adaptation measures and alleviating pressures on human and natural systems are the integration and mainstreaming of climate change in EU policies and building on the corresponding EU instruments, such as river-basin management plans, flood and hazard mapping, structural and cohesion funds, agriculture support, protected natural areas, and spatial planning.

A number of issues appear central to successfully implementing adaptation responses in Europe, including generating adequate funding, building governance structures, providing incentives for the diffusion of innovation, and managing water and land to protect natural systems and preserve vital ecosystem goods and services (World Bank, 2010).

1.2 Regional perspectives

The impacts of climate change vary considerably across Europe, in terms of the regions, territories and sectors affected (see Map 1.1). Vulnerable regions include the Mediterranean basin, north-western and central-eastern Europe and the Arctic, together with many coastal zones and areas prone to river floods, mountains and cities. Even a global temperature increase of 2 °C by the end of this century would still result in major impacts to which the world and Europe need to adapt. The main past and projected impacts, vulnerabilities and hotspots are:

Coastal zones and European seas
The projected sea-level rise and possible increased frequency of severe storm surges may have major impacts on low lying coastal areas across Europe. Observed and projected increases in sea surface temperature will lead to the northward movement of species and changes in the distribution of phytoplankton biomass. Fish stocks in many seas are already under pressure from over-fishing. Allocations of quotas are based on historic catch patterns and these may need to be revised due to climate change.

Mountain areas
The increase in temperature is particularly high in 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 natural hazards such as floods and rock falls that will impact people and the built environment. Key vulnerabilities include reduced winter tourism, less energy supply from hydropower, a shift in vegetation zones, invasive alien species and extensive biodiversity loss. Plant and animal species face the risk of becoming extinct due to natural and artificial barriers not allowing them to move upwards or northwards to more suitable areas. The retreat of the vast majority of glaciers also affects water availability in downstream areas.

Cities and urban areas
European cities are expected to continue to be vulnerable to heat waves, flooding and droughts which may have significant wide-ranging knock-on effects on infrastructures, public health and the economy. The water, energy, building and transport infrastructures are particularly vulnerable.

Mediterranean basin
The Mediterranean basin 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 combined with an ever-increasing demand from the agricultural and the domestic sectors, lower crop yields, increasing risks of droughts and biodiversity loss, forest fires and heat waves. 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.

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 the United Kingdom, Belgium, the Netherlands, Denmark, and Germany. Increases in winter precipitation are projected to increase the intensity and frequency of winter and spring river flooding, although to date no increased trends in flooding have been observed.

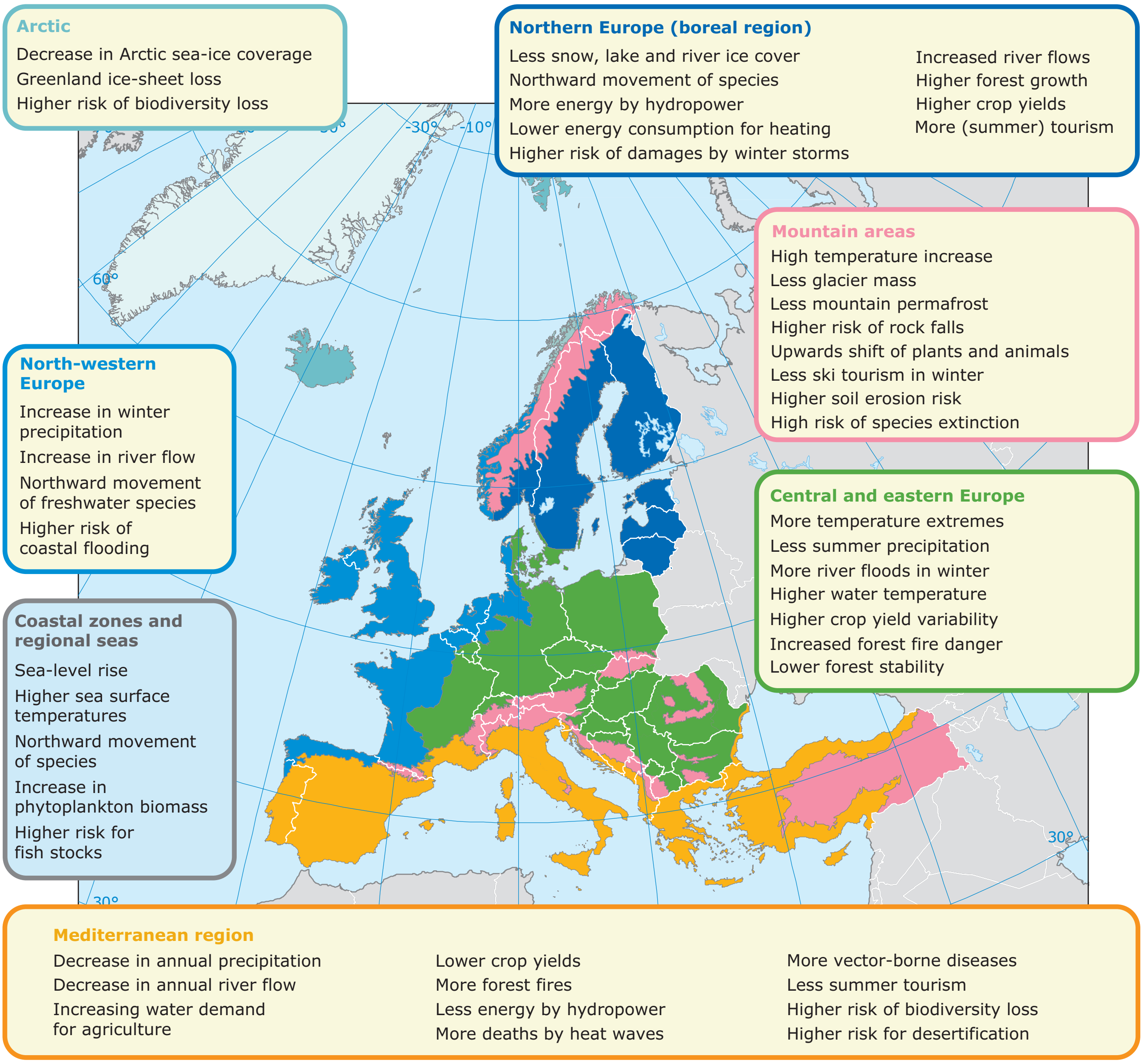
The Arctic
The Arctic faces substantial challenges including a decrease in summer sea ice cover, which is accelerating and projected to continue to impact the local natural and human systems as well as open up business opportunities that could put an additional burden on the environment

such as enhanced 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 ecosystems have suffered significantly from above-average temperature increases and this is expected to continue, even at the 2 °C limit of global temperature increase.

Central and eastern Europe

Temperature extremes are projected to be a key impact in central and eastern Europe together with reduced summer precipitation, increased risk of droughts, increasing energy demand in summer and increased intensity and frequency of river floods in winter and spring although so far no increased trends in river floods have been systematically observed. Climate change is also projected

Map 1.1 Key past and projected impacts of climate change and effects on sectors for the main bio-geographical regions of Europe



Note: Please note that some of the original biogeographical regions of Europe have been regrouped as follows:
Central and eastern Europe: Continental region minus north/west of Italy plus Pannonian region and Steppic region;
Mountain areas: Alps plus Apennines plus Balkans-Rhodope Mountains plus Carpathian plus Fennoscandian plus Pyrenees plus Anatolian region plus Dinaric Alps;
Mediterranean region: Mediterranean region plus Black Sea region and north/west of Italy;
North-western Europe: Atlantic region;
Greenland does not belong to a biogeographical region of Europe.

Source: Based on EEA-JRC-WHO, 2008.

to lead to higher crop-yield variability and increased occurrence of forest fires.

Northern Europe
Less snow and lake and river ice cover are projected to combine with increased winter and spring river flows and greater damage by winter storms. Climate change could offer opportunities in northern Europe, at least in the short and medium terms, such as increased crop suitability and yields, enhanced forests growth, more energy generated by 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.

1.3 Uncertainties and information gaps

There is a continuing need to address uncertainties in climate change assessments, and impacts, vulnerabilities and adaptation are no exception. Incomplete knowledge about and insufficient observed trends in past and current climate change together with uncertainties about future climatic and socio-economic developments typically affect analytical assessments (EEA-JRC-WHO, 2008). This informational uncertainty can only be reduced to some extent as there are areas where reasonable amounts of information are available. Nonetheless others suffer from the lack of a comprehensive evidence base.

Various types of uncertainty can be observed, including scientific and methodological ones. For example there are still challenges in fully understanding the dynamics of glaciers and their melting, and projections are subject to uncertainty as to the model used, the input data and the assumptions about socio-economic variables such as gross domestic product (GDP) and population. However, more sophisticated models and projects have been developed in recent years to quantify key uncertainties (e.g. stochastic models and probabilistic projections). For example, IPCC AR4's projections show that a 50 % reduction in global GHG emissions by 2050 would give a 50 % long-term chance of remaining below a 2 °C increase in global temperature compared to pre-industrial levels.

The body of evidence on scientific and methodological uncertainties suggest that further EU-funded and national research is needed to fill the gaps on methods, models, data sets and forecasting tools, with the aim of improving the understanding of current and expected climate impacts and further identifying vulnerabilities and adaptation options.

The precautionary principle could be invoked where urgent measures are needed in the face of a possible danger to human, animal or plant health, or to protect the environment where scientific data do not permit a complete evaluation of the risk. The measures resulting from recourse to the precautionary principle might take the form of a decision to act or not to act, depending on the level of risk considered acceptable. The EU has applied this principle in various environmental and health areas to make sure that lack of knowledge cannot be used as an excuse for inaction. In addition, although downscaled climate change impacts at the regional and local levels and vulnerability assessments are needed to properly inform adaptation policies, an increasing number of adaptation options are now available, such as no-regret measures that are relevant under all plausible future scenarios.

Policymakers, together with all stakeholders, will inevitably have to make decisions in spite of great uncertainty. Therefore uncertainty and lack of knowledge has to be integrated more systematically into decision-making processes in order to design flexible and robust adaptation policies, which can follow the approach of adaptive management.

2 Climate change vulnerabilities

2.1 Inland water

Glaciers and headwaters

Glaciers are an important freshwater resource and act as water towers for lower-lying regions. Projected changes in precipitation, snow-cover patterns and glacier storage will alter run-off regimes, potentially leading to higher water stress in summer, floods and landslides in winter and higher inter-annual variability. This will have serious consequences for freshwater supply, river navigation, ecosystems fed by water from rivers, irrigation facilities, and power generation. Observed and projected reductions in permafrost, and glacier retreat, are also expected to increase instabilities and natural hazards including glacier lake outbursts, rock-ice avalanches and landslides all of which may damage infrastructure.

The power generation sector, and consumers in general, are particularly vulnerable to changes in water regimes as these will increase the risks of power failure at times of high demand and affect downstream thermal power plants. These could face cooling problems if intake water becomes insufficient or too warm as happened to some French nuclear power plants during the 2003 heat wave. Glacier retreat affects tourism and winter sports and changes the appearance of mountain landscapes. Also hydropower production in the Alpine region will be affected by an increase in sediment discharge into the reservoirs. Furthermore, the solute release from melting rock glaciers may adversely affect the water quality of high mountain lakes through the intrusion of heavy metals.

The European Alps are especially vulnerable to changes in the hydrological cycle and decreases in snow and glacier cover, which are already occurring. Continued glacier melt in the Alps is likely to change the seasonal timing of river discharge in a number of key European river basins including the Danube, Po, Rhine and Rhône. Climate change may worsen current water resource problems and lead to increased risk of conflicts between users in the alpine region — particularly the south — but also outside the Alps where higher water stress is also expected to become more frequent. Projected water shortages and more frequent extreme events, combined with increasing water demand for such activities as irrigation and tourism, are likely to have severe adverse effects on ecosystem services, such as the provision of drinking water. Furthermore, up to 60 % of mountain plant species could face extinction by 2100 if they are unable to adapt by moving northward or uphill. Economic sectors, including agriculture, energy production, forestry, tourism, river navigation and households, are already vulnerable to water shortages.

River floods

Floods ([5]) are complex processes of extreme discharge that involve socio-economic and physical factors. The latter are strongly connected to the hydrological cycle, which is currently being intensified by changes in temperature, precipitation, glaciers and snow cover, all linked to climate change. However, other factors such as land-use changes, water management practices and extensive water withdrawals have considerably changed the natural flows of water, making it difficult to detect climate change-induced trends in hydrological variables. In general, annual river flows have been observed to increase in the north and decrease in the south, a trend that is projected to increase. Projected changes in precipitation regimes will also contribute to altering the intensity and frequency of rain-fed floods and possibly also of flash floods.

Projected climate-induced changes in the hydrological cycle will also increase the impact of other stresses such as land-use and socio-economic changes on water availability, freshwater ecosystems, energy production, navigation, freshwater supply and use by agriculture, households, industry, and tourism.

In the past, the recorded number of river floods has been strongly influenced by improved monitoring and reporting systems. For example since 1990, 259 major river floods have been reported in Europe, of which 165 have been reported since 2000. According to CRED (WHO-EMDAT, 2009) in the years 1998–2008 floods have resulted in more

([5]) Different kind of floods can be distinguished. Apart from coastal floods (see Section 2.2), the most important kind of floods discussed here are: (1) fluvial floods including flash floods (flooding of land by waters originating from part of a natural drainage system, including natural or modified drainage channels and lakes) and (2) pluvial floods (flooding of land directly from rainfall water falling on, or flowing over, the land).

than 700 fatalities, 2.2 million affected people and direct economic losses of more than EUR 55 billion at 2008 values.

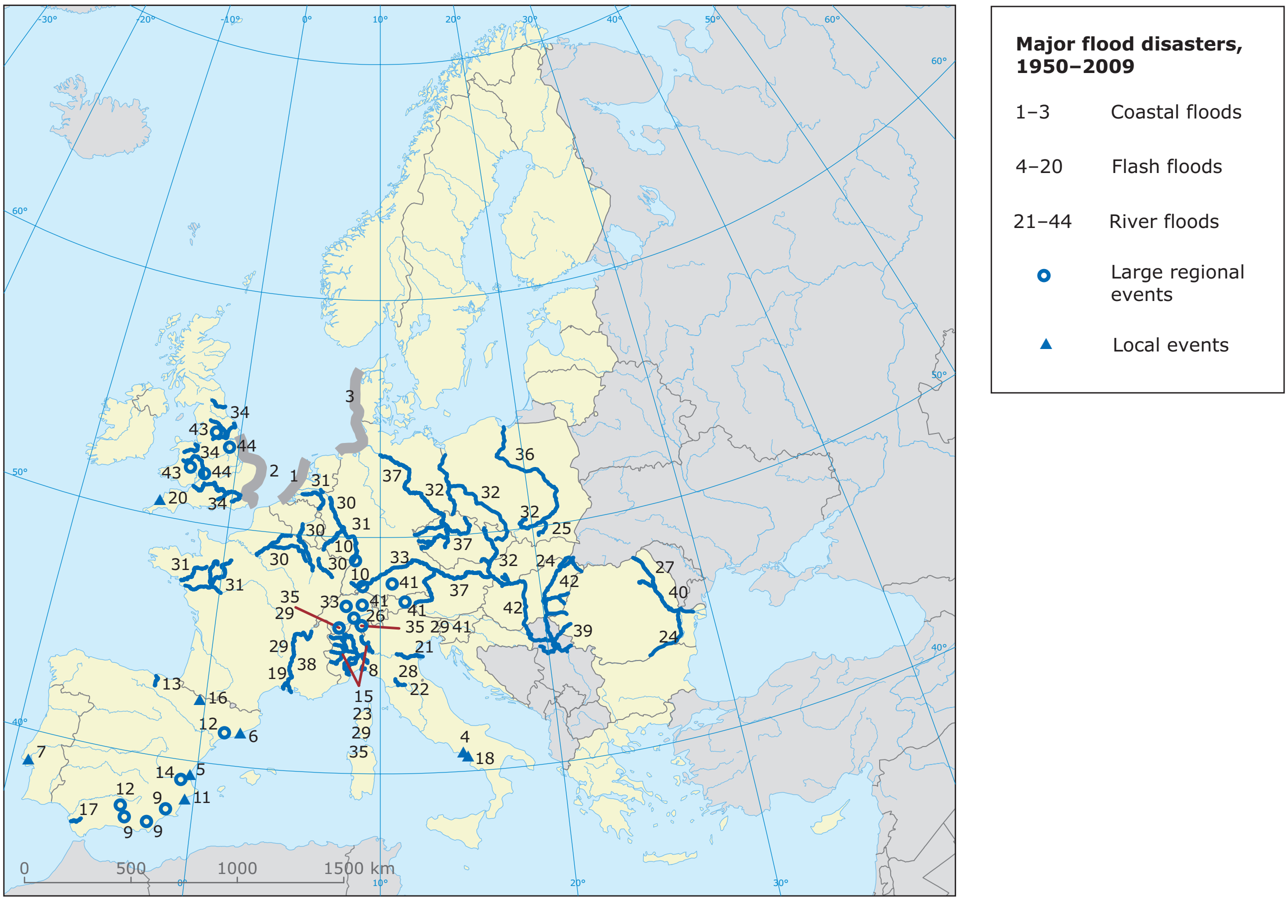
Twenty-two major disasters occurred in the period 2003–2008 alone, resulting in more than 200 fatalities and direct economic losses of about EUR 17 billion. Exceptional disasters were the floods in the United Kingdom in summer 2007, costing more than EUR 5.4 billion; the floods in Switzerland, Austria and Germany in 2005 causing damage valued at EUR 2.7 billion; and the winter storm and flooding affecting France in December 2003, causing losses of EUR 1.5 billion.

Economic losses from floods in Europe have risen over the years. Since the 1970s Europe has enjoyed an increasing standard of living and real per person wealth, all of which has increased the financial exposure of people and assets in flood-prone areas. Improved data collection and reporting of events have also contributed to the upward trends in the number of disasters and the size of economic losses.

Figure 2.1 shows normalised ([6]) flood economic losses in Europe between 1970 and 2008 — the year with the greatest normalised losses is 1983, followed by 2002 and 1997 — and suggests there is no significant trend or influence of anthropogenic climate change. This indicates that socio-economic factors and increasing exposure were the main contributors to the upward trend in flood losses.

Map 2.2 shows an estimate of the riverine flood damage potential or exposure in Europe, which reflects the maximum possible damage in a flood-prone area for a

Map 2.1 Major flood disasters in the EU, Switzerland and Norway, 1950–2009

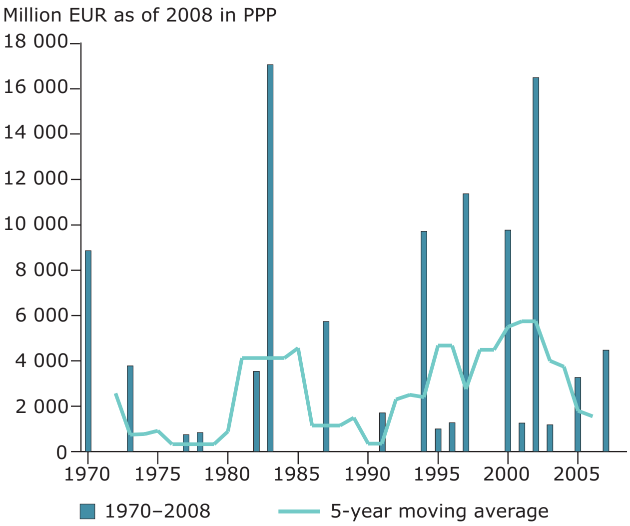


Note: Large regional events are those usually affecting several river basins with flooded areas possibly extending over more than one country and producing widespread flooding. A disaster is classified as major if the number of fatalities is more than 70 and/or direct economic losses are greater than EUR 700 million as of 2009. Baseline data: Em-dat, Munich Re and Dartmouth Flood Observatory.

Source: Updated from Barredo (JRC), 2007.

([6]) Normalisation filters out the influence of socio-economic effects on the loss time series, and aims to assess what the magnitude of economic losses would be if floods from the past were to recur under current societal conditions.

Figure 2.1 Normalised flood losses in Europe from major flood disasters

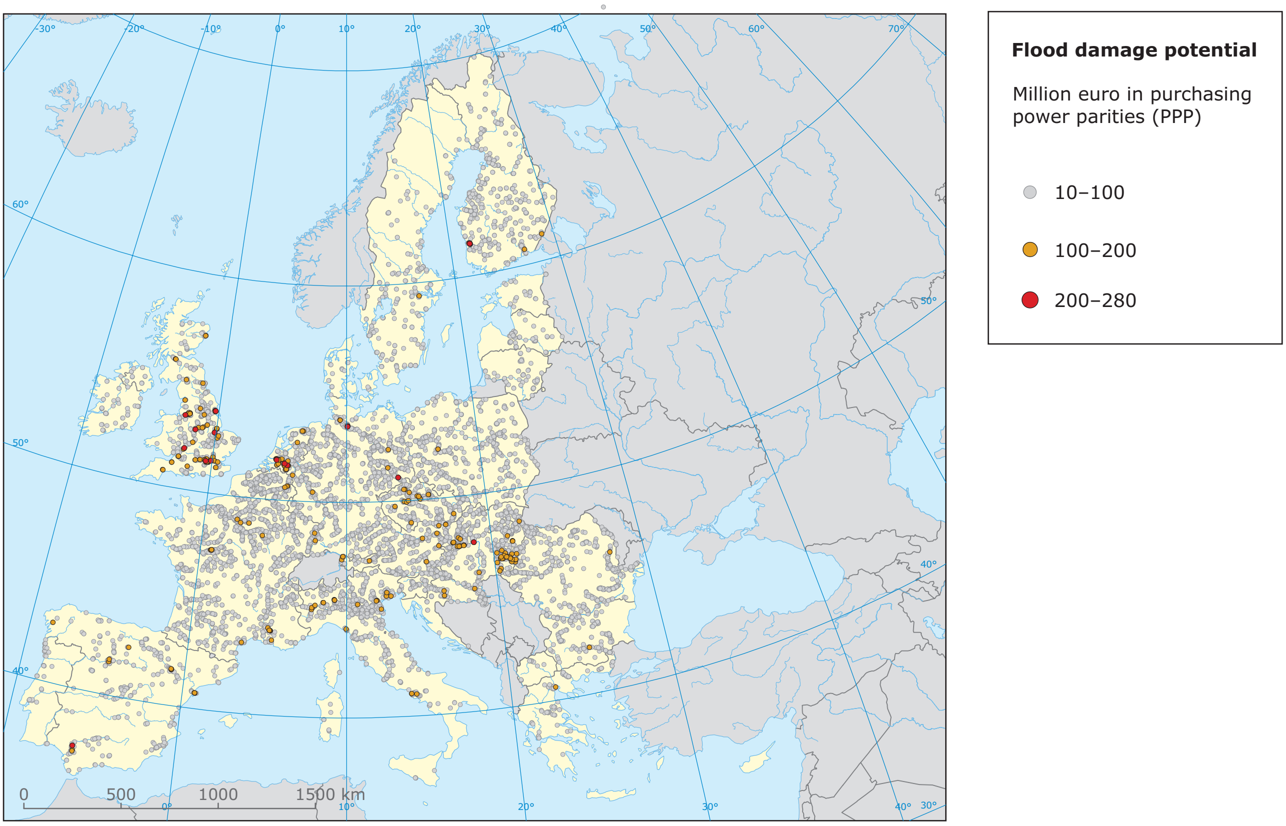


Source: Updated from Barredo (JRC), 2009.

100-year return period. More comprehensive assessments, for example of risks, require information on flood defences and protection measures that are not yet available for all European countries.

Map 2.3 shows an evaluation of possible future flood damage due to climate change, assuming no adaptation or disaster risk reduction measures (Feyen et al., 2010) ([7]). Results from the Projection of Economic impacts of climate change in Sectors of the European Union based on bottom-up Analysis (PESETA) study indicate that flood damage is projected to rise across much of Western and Central Europe while decreases in flood damage are consistently projected for the North-eastern Europe (Ciscar et al., 2009). The current expected annual economic damage for the EU-27 is about EUR 6.4 billion and is projected to rise further, depending on the scenario, to EUR 14–21.5 billion by 2100 at constant 2006 prices. Depending on the scenario, the number of people expected to be affected annually by flooding — currently about 200 000 people — is projected to rise to about 250 000–400 000 each year by the 2080s.

Map 2.2 Riverine flood damage potential

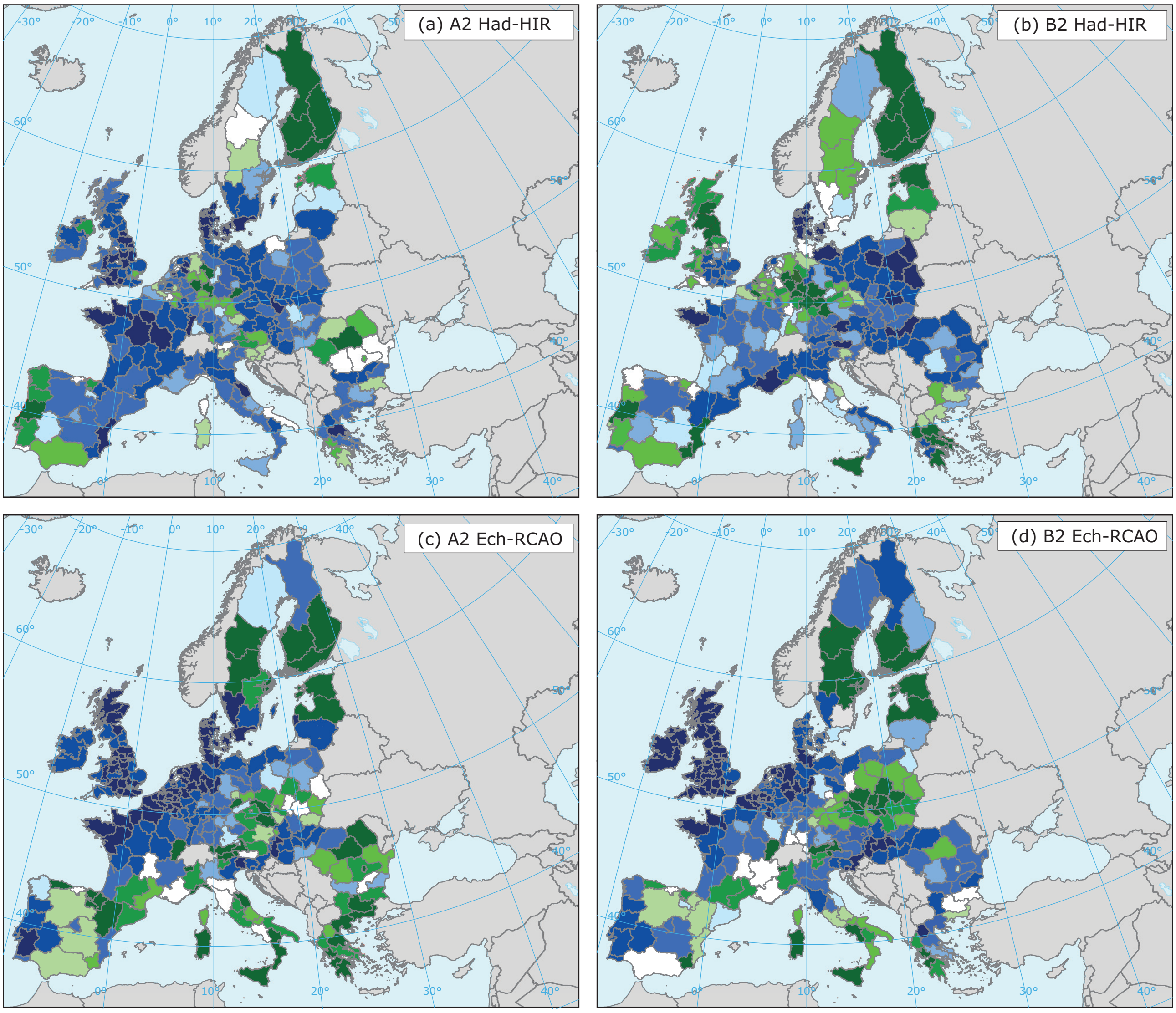


Note: 100-year return period, current climate and no defences; catchments and sub-catchments of less than 500 km^2 are not included.

Source: Barredo, Salamon, Feyen, Dankers, Bódis and De Roo (JRC), 2008.

([7]) Flood risk is defined as the product of flood probability (or hazard), exposure of capital and population, and vulnerability to the effect of flooding based on land-use information and an assessment of flood inundation extents and depths.

Map 2.3 **Expected impact of climate change on future flood damage**



Relative change in expected annual damage (EAD) between scenario (2071–2100) and control period (1961–1990) (%)

< – 75
– 74 to – 50
– 49 to – 25
– 24 to – 10
– 9 to 10
11 to 25
26 to 50
51 to 150
151 to 400
> 400
Out of model

Source: Feyen et al., 2010.

Finally, extreme events such as floods can cause additional impacts by triggering technological disasters such as oil or toxic spills from the chemical industry and other industrial accidents. This phenomenon, known as natural hazards triggering technological disasters (NATECH), has been observed for several natural hazards in recent years. Important events include flooding and associated toxic spills, for example the Aude/Malvesi dam failure in France in 2004, and earthquakes including the 1999 Marmara earthquake in Turkey. The projected increase of frequency and intensity of extreme events in combination with current and expected socio-economic developments might thus increase the frequency of NATECH incidents.

Droughts and agriculture

Droughts are projected to increase, particularly in the south of Europe and in summer. Extreme low discharge levels are projected to become more frequent by 2100 and will have knock-on effects on river navigation, water supply, energy supplies through reduced hydropower and problems with cooling water availability and agriculture in several regions in Europe (Feyen and Dankers, 2009; Feyen and Dankers, 2010).

Already today, crop production is at least moderately water limited — defined as a ratio of actual to maximum production of < 0.7 — in many regions and especially in the south (Map 2.4). Over most of the Mediterranean region, actual production is less than half the production that would be possible in the absence of water limitation — a ratio of < 0.5: in contrast, crop production is hardly water limited in northern and north-western Europe where the ratio is > 0.8.

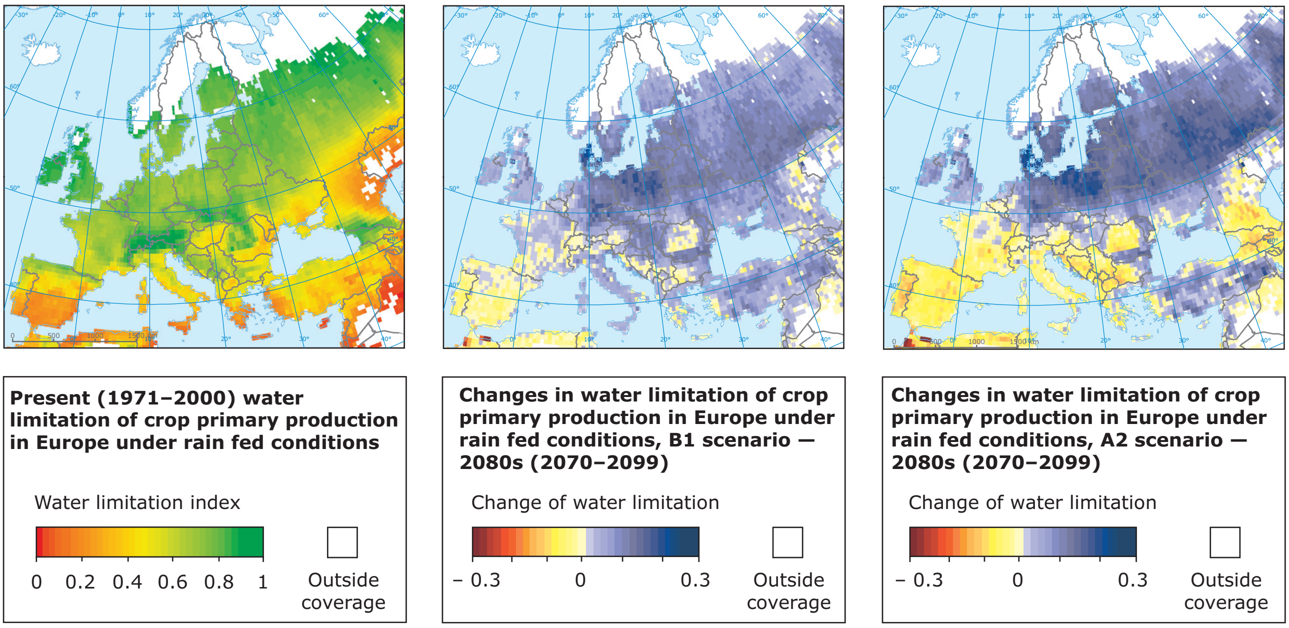
Crop water limitation is projected to worsen across the southern part of Europe, especially under the A2 scenario (see Map 2.4). This indicates that if no adaptation measures are put in place, crop yields will decline due to increases in water shortage ([8]). Adaptation can encompass improved water use in rain-fed agriculture, increases in irrigated areas, and/or increases in irrigation efficiency. While water resources that can potentially be used for irrigation will diminish in the regions for which crop water limitation is projected to increase, the absolute demand for irrigation is expected to increase and lead to water scarcity problems.

In the temperate and northern latitudes, a water-driven increase in crop production is likely to occur. Rising temperatures will also increase yields due to shifts in the timing and length of growing periods in northern latitudes and, generally, crop types and varieties will have to be altered to adapt to the changing climate.

Water scarcity [9]

In addition to climate-driven future changes in the physical water supply, the demand for water is also likely to change due to demographic, economic, technological

Map 2.4 Water limitation of crop primary production in Europe under rain-fed conditions



Note: The crop water limitation index is expressed as the ratio between actual and theoretical (unlimited water) production averaged over all crop types — and its projected changes under IPCC B1 and A2 climate and emissions scenarios in absolute change in the crop water limitation index. The values represent the average over the growing period for all crop types present in a grid cell. Note that no adaptation is assumed and that in regions that are irrigated today (not considered here) the ratio is likely to be close to 1. Based on the LPJmL (Lund-Potsdam-Jena managed Land Dynamic Global Vegetation and Water Balance Model) vegetation and water balance model using the ensemble mean from 21 General Circulation Models (GCMs) that took part in the 4th IPCC Assessment (Randall et al., 2007).

Source: Gerten, 2009.

([8]) Effects of climate change on crop water limitation and resulting yields would be even more adverse in the absence of the carbon dioxide (CO_2) fertilisation effect.

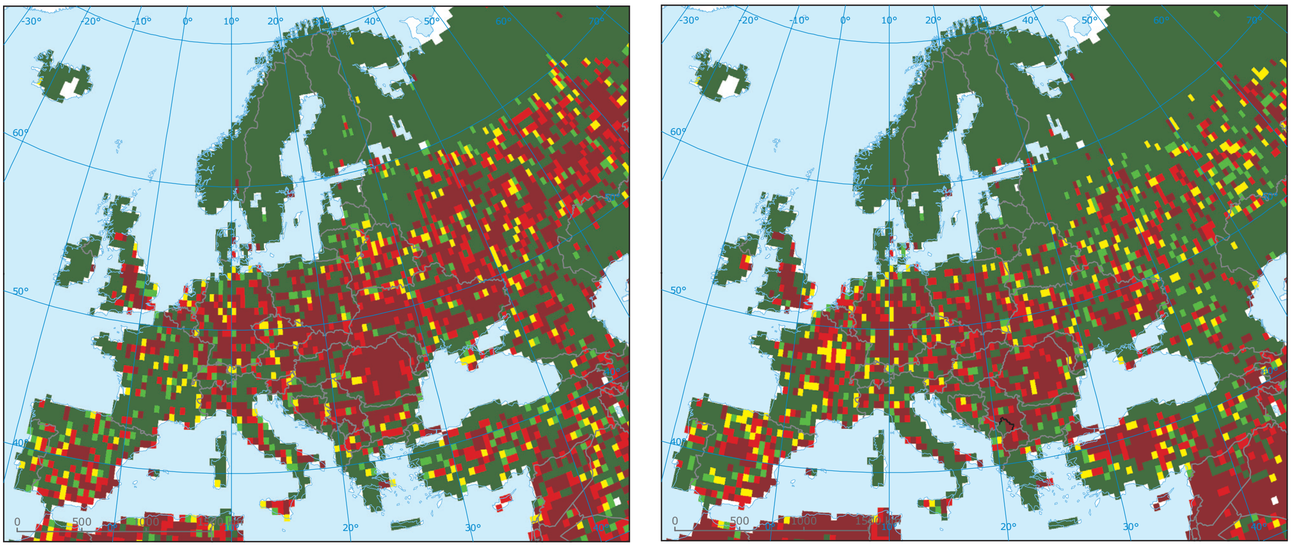
([9]) http://ec.europa.eu/environment/water/quantity/scarcity_en.htm#1. Water scarcity describes a situation of long-term water imbalance, where water demand exceeds the level of resources available. Droughts can be considered to be a more adequate indicator of the state of the environment than water scarcity as they reflects a deviation from natural conditions, whereas water scarcity reflects the imbalance between supply and demand, which is more influenced by socio-economic factors such as high population density or significant volumes of water being used for agricultural or industrial activities.

and lifestyle changes, all in part exacerbated by climate change. In 2000, irrigated agriculture and electricity generation each accounted for about one third of water use — nearly 200 km^3 in total — in Europe; 24 % of water withdrawals were for domestic purposes, and the remaining 13 % were used in manufacturing processes (EEA, 2005). However, notable differences occur between regions, with irrigation being the prime water use in a number of southern European countries, accounting for more than 60 % of withdrawals. Total water use across Europe has been declining since the early 1990s and a further decline by ~ 11 % is projected by 2030, although this is almost exclusively due to the introduction of water-use efficient cooling towers in the power generation sector. Agriculture appears to be the sector that is most vulnerable to climatic changes, at least in southern Europe where projections indicate the need for a significant increase in the irrigated area, but where this additional water will come from remains a critical issue (EEA, 2005).

When looking at water scarcity, large parts of Europe currently appear to be chronically water-short, defined as less than 1 000 m^3 of freshwater being available per person per year (see Map 2.5). While many regions in southern and eastern Europe are water-short due to physical water limitation, water shortages in many Central European regions mainly reflect high population densities. In contrast, in most regions of northern Europe water shortages do not occur on a long-term annual basis, although temporary water shortages may occur in dry years and during the summer season.

Earlier Europe-wide analyses based on the water exploitation index — relative water stress defined as the ratio of water use to availability (EEA, 2005; EC, 2009) — provide similar findings with regard to the regional pattern of water shortage, showing that almost half of Europe's population — concentrated in some south-east and southern European countries, Belgium, England/Wales and Germany — is affected by water stress — a ratio of > 0.4. Studies performed within the Advanced Terrestrial Ecosystem Analysis and Modelling (ATEAM) project (Schröter et al., 2004; 2005) corroborate, at the river basin level, the finding that a large proportion of Europe's population already lives in regions with

Map 2.5 Annual water availability per person (Falkenmark indicator)



Annual water availability per person in present time (1971–2000 average)	
m³/cap/year	
0–500	1 300–1 700
500–1 000	> 1 700
1 000–1 300	Outside coverage

Annual water availability per person for the '2080s' (2070–2099 average, A2 scenario)	
m³/cap/year	
0–500	1 300–1 700
500–1 000	> 1 700
1 000–1 300	Outside coverage

Note: Values less than 1 700 m^3 per person per year indicate water shortage. Based on the LPJmL vegetation and water balance model using the ensemble mean from 21 General Circulation Models (GCMs) that took part in the 4th IPCC Assessment (Randall et al., 2007).

Source: Gerten, 2009.

absolute water stress — less than 1 700 m^3 of freshwater available per person per year.

Water resources, measured as annual precipitation and river discharge, are projected to decline over the whole of South Europe and in the southern parts of Central Europe and to increase in North Europe. This regional pattern is projected to intensify during the later decades of this century (Gerten, 2009). The number of people living in water-short areas is projected to increase by 2100 — changes are usually stronger in the IPCC A2 scenario than in B1. Schröter et al. (2004) find that from the middle of this century population growth and climate change — based on the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (SRES) — will increase the number of people living in river basins characterised by water shortage, especially in the Iberian Peninsula, Italy and in relatively large parts of central Europe. An increased frequency of droughts by the 2070s in most of East and South Europe is also expected (Lehner et al., 2005).

While the water shortage indicators above refer to average annual conditions, water shortages can be much more pronounced in individual seasons, and extreme events such as droughts are likely to be more intense and occur more frequently in many regions (Vörösmarty et al., 2005; UBA, 2008).

2.2 Coastal zones

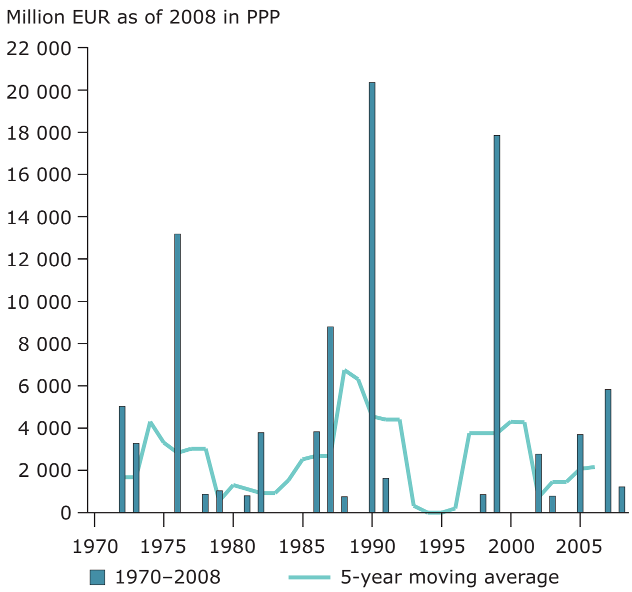
Sea-level rise and changes in the frequency and/or intensity of extreme weather events, such as storms and associated surges, can lead to increased coastal flooding ([10]). A significant and increasing share of the EU population lives in coastal areas — about 19 %, or 86 million people, lives within a 10 km coastal strip (EEA, 2006) and nearly half or about 200 million people (ESTAT, 2009) in regions within 50 km of the coast — and some 140 000 km^2 of land, an area slightly larger than Greece, is currently within 1 m of sea level, which makes it particularly vulnerable to sea-level rise. Significantly inhabited coastal areas in countries such as the Denmark, England, Germany, Italy and the Netherlands are already below normal high-tide levels, and more extensive areas are prone to flooding from storm surges. The OECD (2008) looked at threats to major European coastal cities from a 0.5 metres global average sea-level rise, storm surges and exposure to a 1 in 100 year flood event. The exposed population increases from 2.3 million to 4.0 million in 2100, and the exposed assets, without adaptation measures being implemented, from EUR 240 billion to EUR 1 400 billion — dominated by Amsterdam, London and Rotterdam.

Figure 2.2 shows normalised windstorm losses in Europe, some of which affected coastal zones, between 1970 and 2008. It reveals no particular trend and confirms that increasing windstorm losses are overwhelmingly driven by changing societal and economic factors and increasing exposure, such as increasing standards of living and real wealth per person.

The impacts of sea-level rise on the coastal areas of Europe are expected to be overwhelmingly negative, based on earlier studies and reviews such as Rotmans et al. (1994), Nicholls (2000), de la Vega-Leinert et al. (2000), Nicholls and Klein (2005) and Nicholls and de la Vega-Leinert (2008). The major impacts are expected to be increased flooding and permanent inundation of low-lying coastal areas, increased erosion of beaches and cliffs and degradation of coastal ecosystems. Locally, salinisation may also be important. Coastal morphology and human utilisation will condition the nature of these impacts. Barredo et al. (2009) assessed the exposure or potential economic losses to coastal flooding in Europe (see Map 2.6).

Based on the DIVA model, Hinkel et al. (2009; 2010) assessed the vulnerability of European coastal areas to sea-level rise and storm surge. Table 2.1 gives an overview of the potential impacts at the aggregate level of the

Figure 2.2 Normalised windstorm losses in Europe from major windstorm disasters



Source: Barredo (JRC), 2010.

([10]) Although not linked to climate change, another potentially important source of coastal flooding, particularly in Southern Europe, is tsunamis triggered by strong earthquakes caused by off-shore faults in the Mediterranean Sea.

Table 2.1 People at risk of being flooded, land lost and cost of damage in the EU-27 without adaptation in the medium-long term (SRES A2 and B1 scenarios)

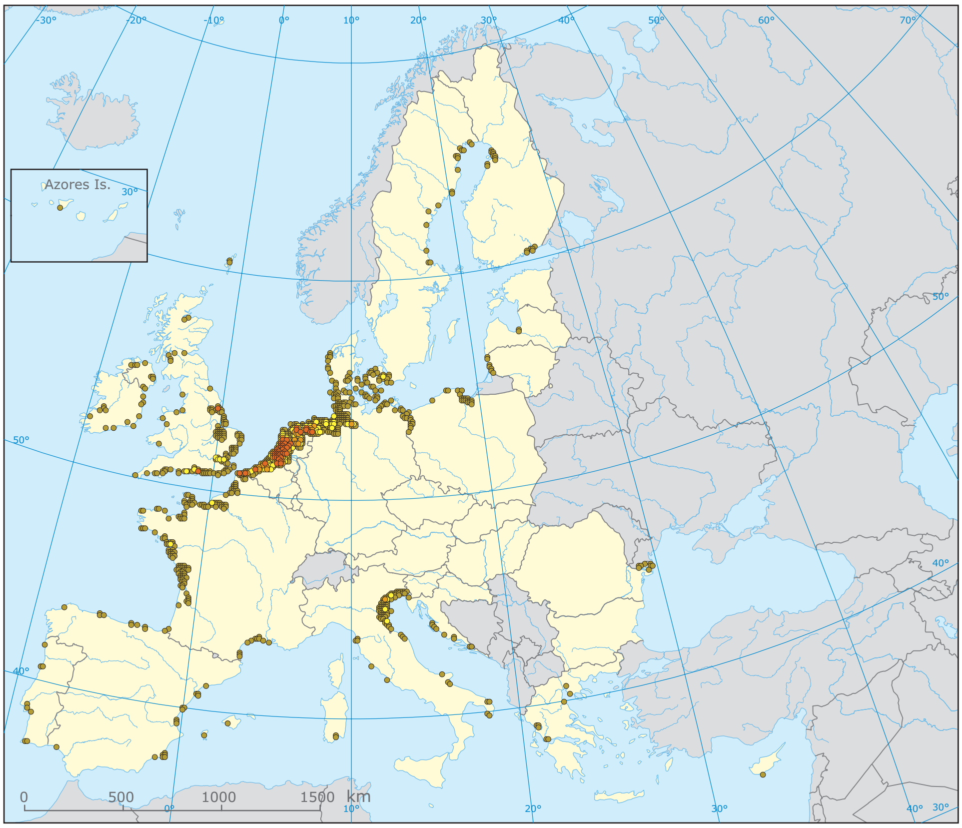
	People at risk of being flooded (thousand/year)	Land eroded and lost (km²/year)	Damage cost (billion EUR/year)
A2			
2030	21	7	4.8
2050	35	10	6.5
2100	776	16	16.9
B1			
2030	20	6	5.7
2050	29	8	8.2
2100	205	12	17.5

Source: Hinkel et al., 2010; 2009.

EU-27 coastal countries for the IPCC A2 and B1 scenarios without adaptation. The expected number of people at risk of being flooded annually grows significantly, in particular during the second half of the century, reaching about 0.8 or 0.2 million in 2100 under A2 and B1 respectively, which is about 0.13 and 0.04 % of the projected EU-27 population — 70 and 20 times higher than in 2000.

Differences in social damage between the two simulations are minor until 2050, reflecting the small differences in sea-level rise and socio-economic development and the inevitability of impacts irrespective of mitigation measures. Map 2.7 shows that the countries most affected are expected to be France, Latvia, the Netherlands and the United Kingdom. Agricultural land loss due to coastal

Map 2.6 Coastal flood damage potential



Coastal flood damage potential

Million EUR in purchasing power parities (PPP)

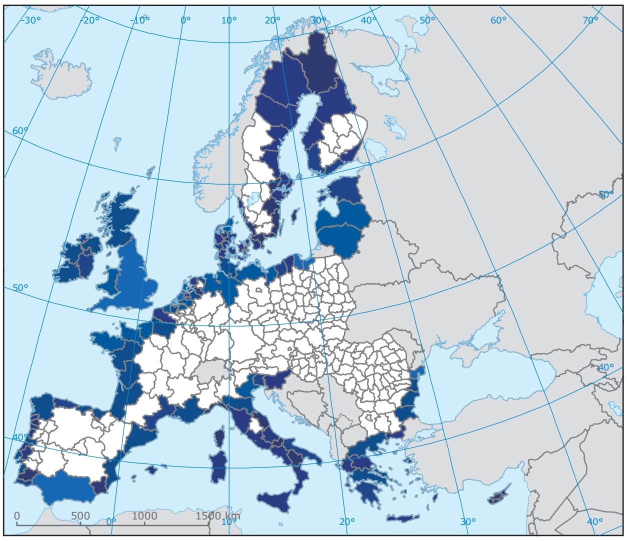
- < 1 000
- 1 000–2 000
- 2 000–3 000
- > 3 000

Note: 100-year return period storm-surge, current climate and no defences.

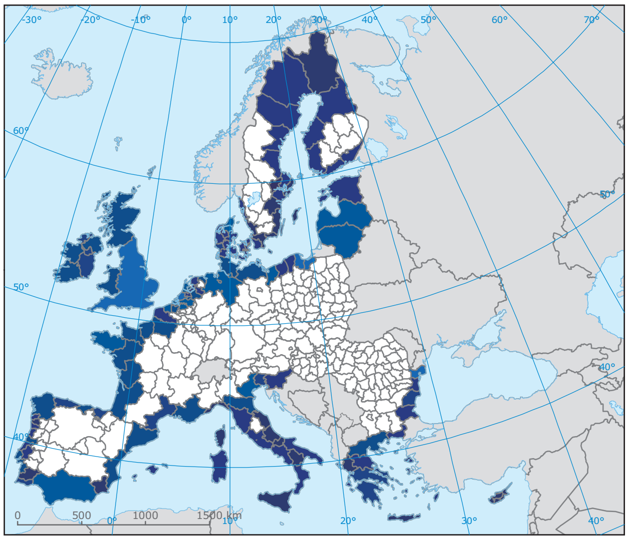
Source: Barredo, Salamon and Feyen (JRC), 2009.

Map 2.7 People expected to be at risk of flooding without adaptation in the medium-long term

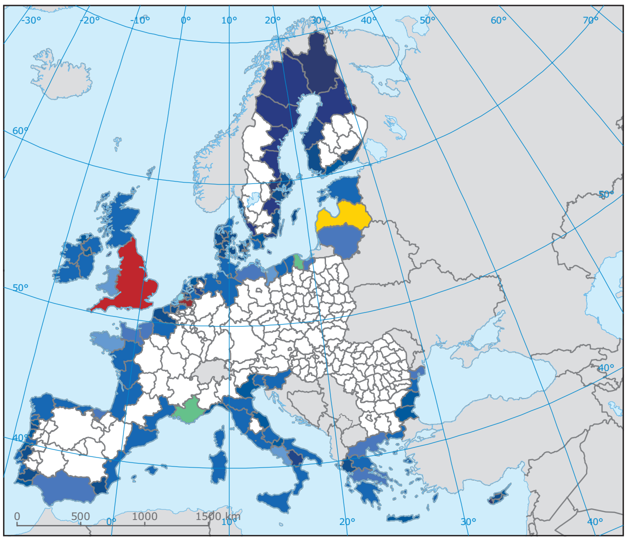
People flooded under the A2 scenario, 2050



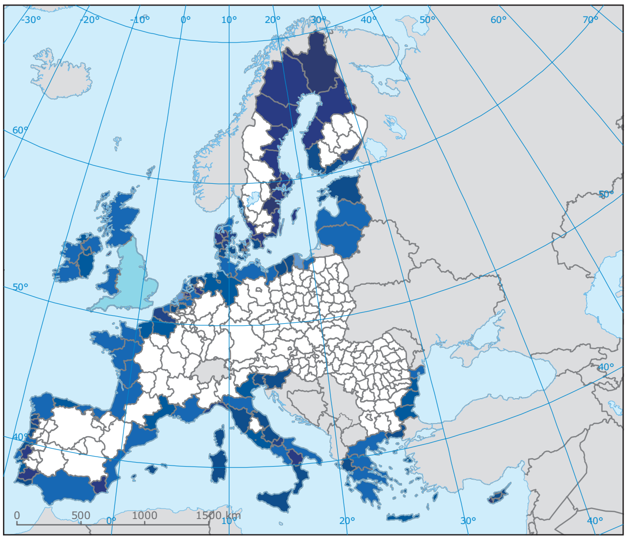
People flooded under the B1 scenario, 2050

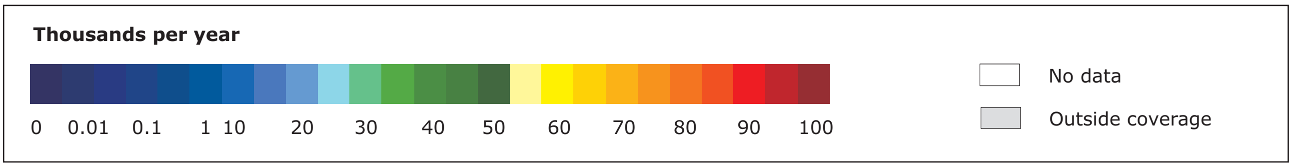


People flooded under the A2 scenario, 2100



People flooded under the B1 scenario, 2100





Source: Hinkel et al., 2010; 2009.

erosion is relatively small and is concentrated in a few regions such as Denmark, Estonia, France, Germany, and the Netherlands.

The costs of damage increase roughly by a factor of five by 2100 from today's level under both scenarios (Table 2.2). Damage is slightly higher under B1 because it assumes exposure grows faster — the higher sea-level rise under A2 is compensated for by lower GDP growth, reducing the cost of damage. Under both scenarios, total damage costs do not exceed 0.04 % of European coastal countries' GDP in 2100. The major contributors to these costs are sea

Table 2.2 Contribution of the different impacts to the total damage cost in the EU-27 without adaptation in the medium-long term (SRES A2 and B1 scenarios)

Million EUR/year	Salinity intrusion	Land eroded and lost	Sea floods	River floods	Migration	Total damage cost
A2						
2030	1 005	4	3 501	36	218	4 767
2050	1 147	7	4 861	63	371	6 450
2100	2 010	16	13 637	283	986	16 933
B1						
2030	1 122	4	4 274	44	223	5 662
2050	1 326	7	6 398	79	386	8 192
2100	1 844	10	14 483	274	884	17 496

Note: Differences between total damage cost and sum of columns are due to rounding.

Source: Hinkel et al., 2010, 2009.

floods, about 75 %; salt intrusion in deltas and estuaries, about 20 %; and migration, about 5 %, resulting from land lost due to coastal erosion, particularly towards the end of the century.

Costs are by far the highest in the Netherlands, EUR 5.4 billion or 0.3 % of GDP under A2 by 2100, followed by France, Germany, and the United Kingdom with costs around EUR 2 to 3 billion in 2100. Damage costs relative to national GDP do not exceed 0.1 % other than in the Netherlands.

2.3 Terrestrial biodiversity and ecosystems

Changes in land use and land management, together with urbanisation, industrialisation, over-exploitation, pollution and unsustainable practices, have resulted in the fragmentation, degradation and destruction of habitats and caused widespread species losses (EC, 2010a). Climate change is exerting an additional pressure on biodiversity, which is likely to exacerbate these losses. A combination of climate change and these other drivers of change could result in substantially different ecosystems and landscapes across Europe leading to local, regional and global extinctions.

The European Commission is seeking to address the decline in Europe's biodiversity and secure ecosystem services by reducing the impacts of different drivers of change and enhancing the ability of ecosystems to adapt to climate change. New areas for conservation will be required, together with measures to improve the connectivity of fragmented landscapes to aid the migration, dispersal and genetic exchange of species. Article 10 of the Habitats Directive provides an appropriate policy mechanism through which to strengthen the coherence of the European ecological network of Natura 2000 sites (EC, 1992). A review of international, European and Member State guidance on adaptation for the Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention) Group of Experts on Biodiversity and Climate Change identified a set of principles for developing adaptation strategies and actions to conserve species, habitats and ecosystems and the services that they provide (Harley and Hodgson, 2008). Of these, enhancing ecosystem resilience to enable coping and recovery from change, and using adaptive conservation management as a flexible approach in an uncertain future are of particular importance.

A recent study for the European Commission — Biodiversity and climate change in relation to the Natura 2000 network — assessed the vulnerability to climate change of 25 % of the species of Community Interest, identified under the Habitats and Birds Directives (Sajwaj et al., 2009). Most of these are rare and have specific habitat requirements or are otherwise threatened, and many currently have unfavourable conservation status. The study developed and applied an approach that goes beyond the estimation of potential impacts — the combined effects of exposure and sensitivity to climate change — by also considering the biological adaptation options of each species. The results show that the vast majority of species in each taxonomic group studied — breeding birds, reptiles and amphibians, butterflies and vascular plants — are likely to be vulnerable to some extent and very few are likely to benefit from climate change, even when modelled projections suggest there will be an expansion in suitable climate space. The results also show that vulnerability primarily arises because many species will be constrained in their ability to move to and colonise new areas with suitable climate because of, for example, limited dispersal abilities, lack of suitable habitat, or low levels of emigration due to small population sizes. Because of these constraints, a significant proportion of species have a high to extremely critical level of vulnerability, particularly beyond 2080.

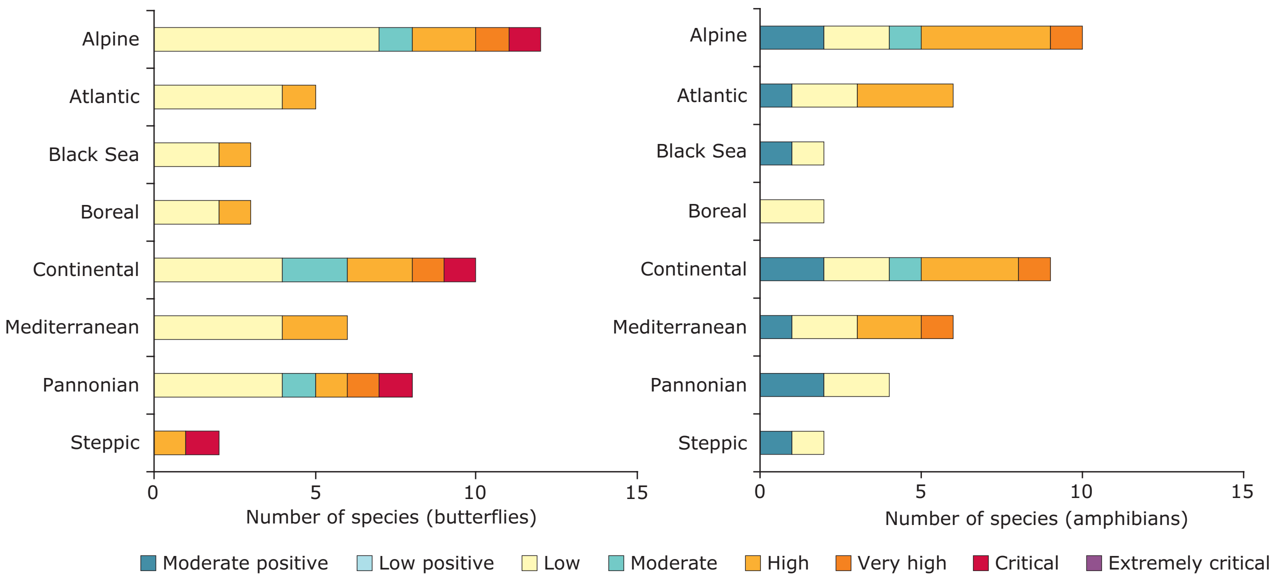
The vulnerability assessments were then linked to the spatial occurrence of these species across the Natura 2000 network and then to climate change projections to identify the regions and sites that are likely to face the most significant threats (Bertzky et al., 2009). The results help to identify areas where adaptation actions are needed. These may need to focus on regions that host a large number of species assessed to have a high to extremely critical level of vulnerability (see Figure 2.3). The species that are reported to occur in only a very few Natura 2000 sites are also likely to require special attention. In addition, the occurrence of such species outside designated sites might need to be considered in the design of landscape-scale conservation activities. There is clearly a need to assess the vulnerability of more species of Community Interest to gain a better understanding of the robustness of the Natura 2000 network and to support the adaptation efforts of Member States.

2.4 Economic sectors

Agriculture and forestry (11)

The length of the growing season of several agricultural crops has increased in northern latitudes, favouring the introduction of new species that were not previously suitable. However, there has been a shortening of

Figure 2.3 Occurrence of assessed butterfly and amphibian species of different vulnerability categories in bio-geographical regions, 2050, A2 scenario



Source: Bertzky et al., 2009.

Box 2.1 European forest ecosystem services

European forest ecosystems provide a wide range of environmental and socio-economic services, which vary regionally and according to their particular location. Environmental services include: regulation of climate and freshwater; protection of biodiversity and soils; and reduction of flood risks. Socio-economic services include: provision of jobs, income, and raw materials for industry and renewable energy; protection of settlements and infrastructure; and improvement in the quality of life. These ecosystems and their services are vulnerable to climate change and vital in adaptation and mitigation actions (EC, 2008a; Lindner et al., 2010). Their climate regulating function could diminish as CO_2 emissions continue to rise. Changes in vegetation and shifts in forest type are also likely to occur (Casalegno et al., 2007). Changes in the timing of life cycle events of pests and pollinators and the introduction of new pathogens and alien species may present additional challenges. Warmer and dryer conditions will increase the risk of forest fires and lead to longer fire seasons especially in southern and central Europe (Camia et al., 2008). Destructive storms are also likely to become more frequent.

(11) It should be noted that the terms 'forestry' and 'forest sector' refer to the use of forests for productive functions.

the growing season locally at southern latitudes. The flowering and maturity of several species in Europe now occurs two or three weeks earlier than in the past with consequent higher risk of frost damage from delayed spring frosts. Changes in the growing season and the timing of the cycle of agricultural crops (agrophenology) are projected to continue.

While the area under arable cultivation in most of Western Europe has decreased over the past 40 years, crop yields have increased almost continuously. Since the beginning of the 21st century, the variability of crop yields has increased as a consequence of extreme climatic events, for example, the summer heat wave of 2003 and the spring drought of 2007. The hot summer of 2003 is estimated to have led to EUR 10 billion losses to European farming, livestock and forestry from the combined effects of drought, heat stress and fire (Munich Re, 2008). Floods and excess water have also had adverse impacts on agriculture.

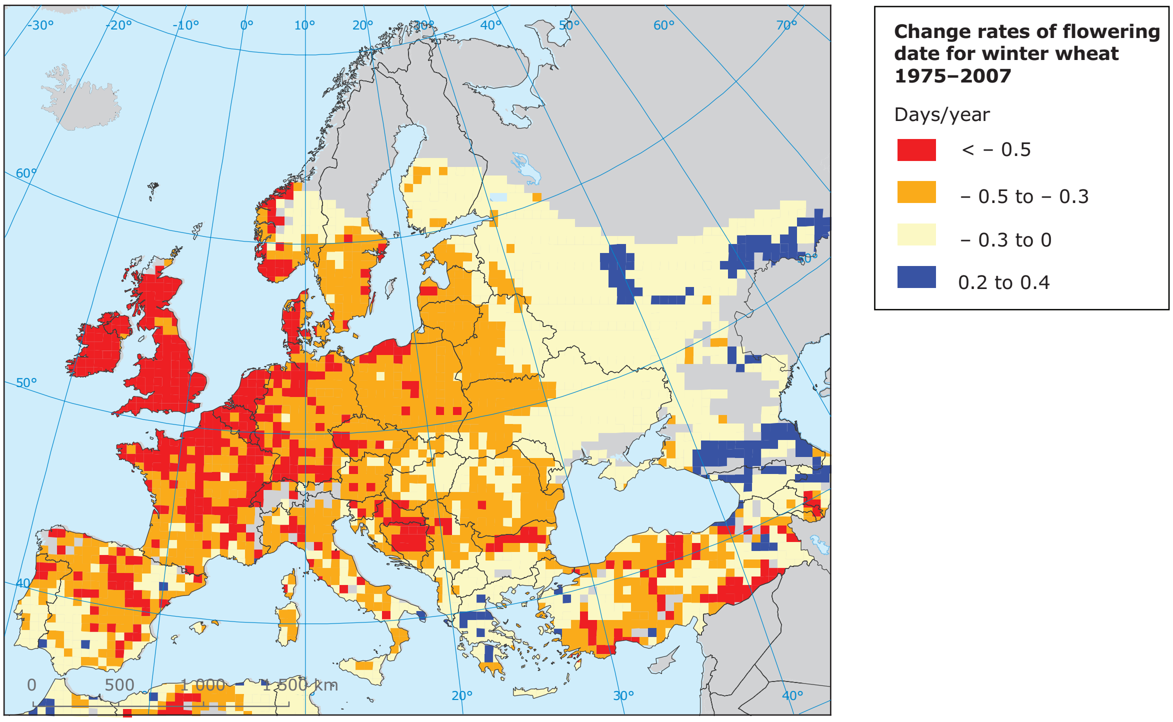
As extreme events are projected to increase in frequency and magnitude, crop yields are likely to become more variable. The PESETA project simulated the effects of various climate change scenarios on agriculture crop yields, including CO_2 fertilisation effects (Iglesias et al., 2009). A fall of 10 % in EU crop yields by 2080s is simulated for the 5.4 °C scenario while little change is projected for lower levels of climate change. By the 2020s, all European regions would experience yield improvements, particularly in northern Europe, and the EU overall yield gain would be about 17 %. However, potential benefits will only emerge from a low level of temperature increase and are highly uncertain (EC, 2009a).

All scenarios share a similar pattern in the spatial distribution of effects by the 2080s, whereby high yield improvements in northern Europe are caused by a longer growing season, while crop productivity decreases in southern Europe are caused by a shortening of the growing period, with subsequent negative effects on grain filling. The British Isles could have either yield losses or gains depending on the specific climate change scenario.

Increases in water demand for agriculture have occurred mainly in Mediterranean areas and this is projected to continue, increasing competition for water between sectors and uses. There is a need for adaptation of farm practices and land management to reduce or avoid adverse climate change impacts. Some of the adaptation options such as irrigation may however increase emissions because of increased energy consumption.

With regard to the forestry sector, some studies of the impacts of climate change in Europe have been undertaken,

Map 2.8 Modelled change of the flowering date for winter planted wheat, 1975–2007



Note: The day of the year of flowering has been simulated using a crop growth model (Crop Growth Monitoring System (CGMS)).

Source: EEA-JRC-WHO, 2008.

but only sparse information on financial losses or adaptation costs is available. Lindner et al. (2010) addressed all bio-geographical European regions and showed that the observed warmer and wetter winters have already had a negative impact on logging and harvesting operations in the boreal region, especially on wetter soils, for example, peatlands. In the Mediterranean region an increase in temperature is likely to lead to a decrease in forest growth. Moreover the projected increased frequency and intensity of fires may lead to a reduction in wood production and timber values in vulnerable areas. Additionally, the projected increase in the intensity and frequency of heavy storms may have serious economic consequences — hundreds of millions of EUR each year — in the forestry sector, as shown by recent events which caused an enormous amount of wind-thrown timber — storms Lothar and Martin in 1999: about 200 million m^3; storm Gudrun in 2005: 66 million m^3; storm Kyrill in 2007: about 59 million m^3. The economic impact of wind damage is particularly severe in managed forests because of the reduction in the yield of recoverable timber, the increased costs of unscheduled thinning and clear-cutting, and resulting problems in forestry planning (EC, 2008a).

Lindner et al. (2010) also demonstrates that adaptive capacity, in a socio-economic sense, varies largely between European regions. Landowners and the forest industry in the boreal region will tackle the impacts of climate change using their long-standing experience in intensive management and related economic interests. In the Mediterranean region, where most of the forests are extensively managed or even unmanaged, adaptive capacity is limited.

Energy

Data on heating degree days shows a fall in recent years in Europe, indicating a benefit from reduced space heating. Actual energy demand from these changes is also determined by technical and socio-economic factors, including behavioural changes. At present, no data are available on cooling degree days across Europe, preventing any systematic assessment of how the cyclical nature of annual energy consumption might be affected. However, country-specific data show some increases in cooling degree days over the same period, consistent with greater space-cooling demand.

Projections of climate change suggest reductions in heating degree days in Europe, but increases in cooling degree days. The net change in energy demand is difficult to predict, but there will be related distribution patterns, with significantly reduced space-heating demand in northern Europe and an increased demand for cooling in southern Europe, with associated costs and benefits. There may also be increases in energy demand associated with adaptation to climate change, for example, for additional transport and supply of water.

The projected change in river runoff due to climate change will result in an increase in hydropower production by about 5 % and more in northern Europe and a decrease by about 25 % or more in the south. Dam safety may be affected under changed climatic conditions with more frequent extreme flows and possible natural hazards. Climate change could have an adverse impact on thermal power production as most studies show that summer droughts will be more severe, limiting the availability of cooling water in terms of quantity and appropriate temperature, and reducing the efficiency of power plants.

Tourism and recreation

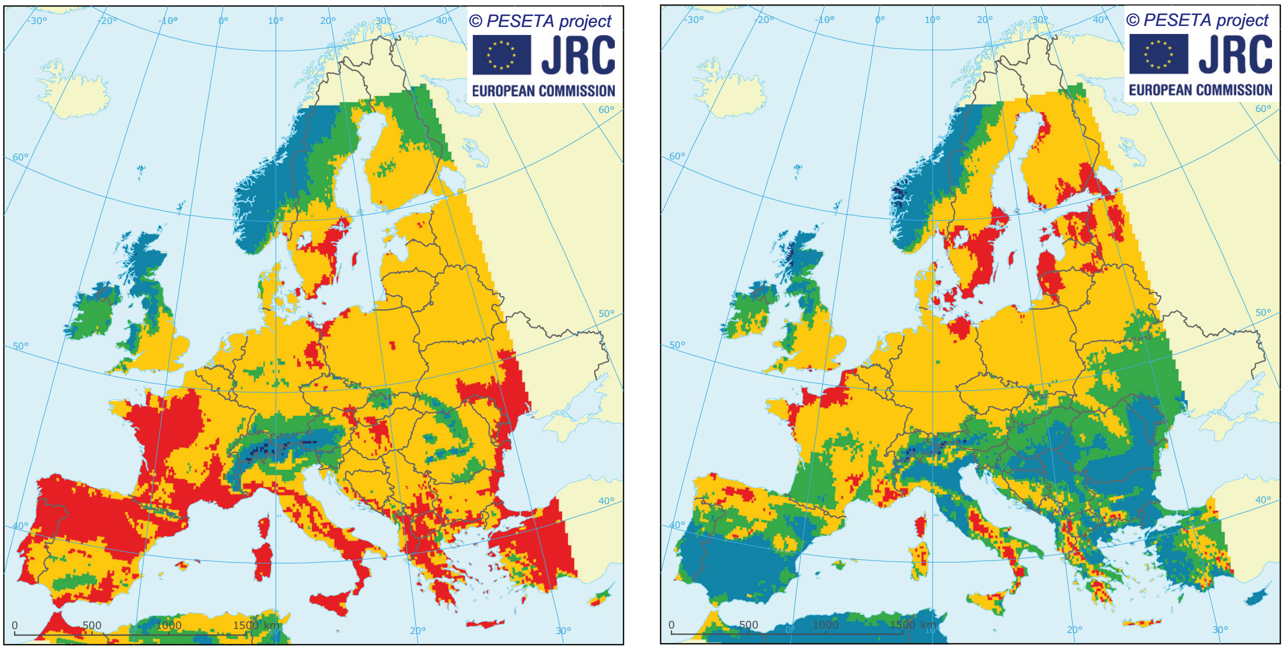
The Mediterranean region is the world's most popular holiday destination: it attracts some 120 million visitors from northern Europe each year, the largest international flow of tourists on the globe, and while there, they spend is more than EUR 100 billion (Amelung and Moreno, 2009). During the key summer months the Mediterranean has a close to ideal climate for tourism, with very high scores on the Tourism Comfort Index ([12]). However, changes in the climate are starting to affect the attractiveness of many of the Mediterranean's major resorts, while improving the attractiveness of other regions, for example resorts offering outdoor activities in northern Europe.

Projections of climate change suggest that the suitability of the Mediterranean for tourism will decline during the key summer months (Map 2.9), though it may increase in the spring and autumn. This could produce shifts in the major flows of tourism within the EU, very important for regions where tourism is key to the economy. Climate change could benefit the Mediterranean tourist industry if it evens out demand, reducing the summer peak while increasing occupancy in the spring and autumn. But without such adjustments, the Mediterranean tourist industry will be among the main casualties of climate change.

Studies also project widespread reductions in snow-cover over the 21st century (IPCC, 2007b) which will affect the winter sports industry across Europe that attracts millions of tourists each year, generating nearly EUR 50 billion in annual turnover (OECD, 2007). Responses are already in place, including artificial snow-making, and this has increased in recent years. However, adaptation options pose

([12]) This index, primarily developed for general outdoor activities, is based on the notion of human comfort and consists of a weighted index of maximum and mean daily temperature, humidity, precipitation, sunshine and wind.

Map 2.9 Modelled conditions for summer tourism in Europe for 1961–1990 and 2071–2100



Simulated conditions for summer tourism in Europe for 1961–1990 (left) and 2071–2100 (right) according to a high-emissions scenario (IPCC SRES A2)

Tourism comfort index (TCI)

- Unfavourable (TCI: 0–40)
- Acceptable (TCI: 40–60)
- Good (TCI: 60–70)
- Very good (TCI: 70–80)
- Excellent (TCI: 80–100)

Source: Ciscar et al., 2009; Amelung and Moreno, 2009.

sustainability and environmental issues such as water use by snow-machines negatively affects current water resources, energy use and associated GHG emissions, all of which need to be assessed.

2.5 Cities and the built environment

Cities are highly vulnerable to the impacts of climate change due to their physical structure and the density of their populations. Current and projected climate change impacts include coastal and river floods, heat waves and droughts (EEA, 2009). These risks further exacerbate the existing environmental problems of many cities and towns, including poor air quality and water supply issues as well as social inequalities as the poor often live in riskier areas within cities and do not necessarily have the adequate resources to cope and adapt.

Exposure to coastal floods is a key challenge for several major European cities (Nicholls et al., 2008; Hallegatte et al., 2008). Heat waves in cities can lead to deaths and also worsen ozone and air quality-related health problems and heat stress, and change the distribution and increase the spread of infectious diseases. Floods and droughts can also lead to water-borne disease outbreaks and increased stress, and may affect mental health.

The vulnerability of cities depends critically on the way urban areas are built. Urban design, and ultimately land cover and land use, can aggravate climate change impacts, for example through soil sealing contributing to the heat island effect and flooding caused by water run-off. Temperatures can differ significantly across a city, with green areas being typically cooler than high-density urban areas, providing better ventilation and water storage potential.

With increasing global temperatures, climate zones will shift northwards and will have major implications for water utilities, health services and urban infrastructure. Buildings that were designed and engineered for cold harsh winters will need to function in a drier and hotter climate, and heritage buildings may suffer irreversible damages.

Extreme events such as flooding or landslides constitute key challenges for infrastructures and the built environment. In cities the continuity of essential services is threatened, specifically in connection with water supply and sewerage, health services and transport.

In mountainous regions for example, the strong retreat of glaciers can cause instabilities resulting in such hazardous incidents as glacier lake outbursts, rock-ice avalanches and landslides, which may cause severe damage to infrastructure. The observed and projected reductions in permafrost are also expected to increase natural hazards and damage to high-altitude infrastructure.

2.6 Human health

Nearly all the environmental and social impacts of climate change may ultimately affect human health through altering weather patterns, and through changes in water, air, food quality and quantity, ecosystems, livelihoods and infrastructure (Confalonieri et al., 2007). Climate change can multiply existing health problems and risks; however health effects depend largely on the specific vulnerabilities of the population and its adaptive capacity. Integration of health issues in mitigation and adaptation measures, policies and strategies, sharing information and knowledge, and best practices are among the strategic objectives of the European Regional Framework for Action adopted at the 2010 World Health Organization (WHO) 5th Parma Ministerial conference (WHO, 2010a).

The 2003 summer heat wave in Europe, with a death toll exceeding 70 000, highlighted the need for adaptation to a changing climate (Robine et al., 2008; WHO, 2009). The elderly and people with some diseases are at higher risk, and socio-economically deprived population groups are more vulnerable (Kirch et al., 2005; EC, 2008b). In congested urban areas with high levels of soil sealing and heat absorbing surfaces, the effects of heat waves can be exacerbated as a result of insufficient nocturnal cooling and poor air exchange (WHO, 2004). For populations in the EU, mortality has been estimated to increase by 1–4 % for each degree increase in temperature above a locally specific cut-off point (WHO, 2008). The PESETA project reported an estimated increase in heat-related mortality resulting from projected climate change of between 50 000 and 160 000 cases per year by the 2080s, mainly in central and southern European regions (Watkiss et al., 2009). The PESETA project also estimated the decrease in cold-related mortality to be between 100 000 and 250 000 cases per year by the 2080s. Once acclimatisation factors are taken into account, these estimates can be substantially reduced, although the short-term and long-term role of acclimatisation is still being debated (WHO, 2004).

Extreme weather events, flooding, precipitation and storm surges, expected to be more frequent and intense in some regions of Europe, can result in more potential casualties, and wider effects on mental health and well being. For example, in Scotland, intangible social impacts, such as living in temporary accommodation and dealing with insurers, were more severe than the material losses, particularly among the elderly. Increased run-off and the loading of coastal waters with pathogens, nutrients and toxic chemicals can pose risks, in particular in highly built-up coastal areas (Semenza and Menne, 2009). Changing climatic conditions are also suggested to affect the environmental distribution and toxicity of some chemical pollutants (Noyes et al., 2009).

An anticipated impact of climate change on the spread of water-, food- and vector-borne ([13]) diseases (see Box 2.2) in Europe emphasises the need for tools to address these threats to public health (Semenza and Menne, 2009; ECDC, 2010). A shift in the distribution of ticks, vectors of Lyme disease and tick-borne encephalitis (TBE) to higher altitudes and latitudes has been linked to climate change. Transmission patterns of communicable diseases are also influenced by ecological, social and economic factors, access to health care, early detection and preventive measures. Changing land-use patterns, increased numbers of large animal hosts, expansion of rodent habitats, alterations in outdoor human activity, and vaccination coverage are considered to explain the observed heterogeneity in the increased incidence of TBE in Europe (Semenza and Menne, 2009).

Projections of malaria under future climate change scenarios are limited in Europe. Nonetheless, the risk of reintroducing malaria into Europe is very low and determined by variables other than climate change (Semenza and Menne, 2009).

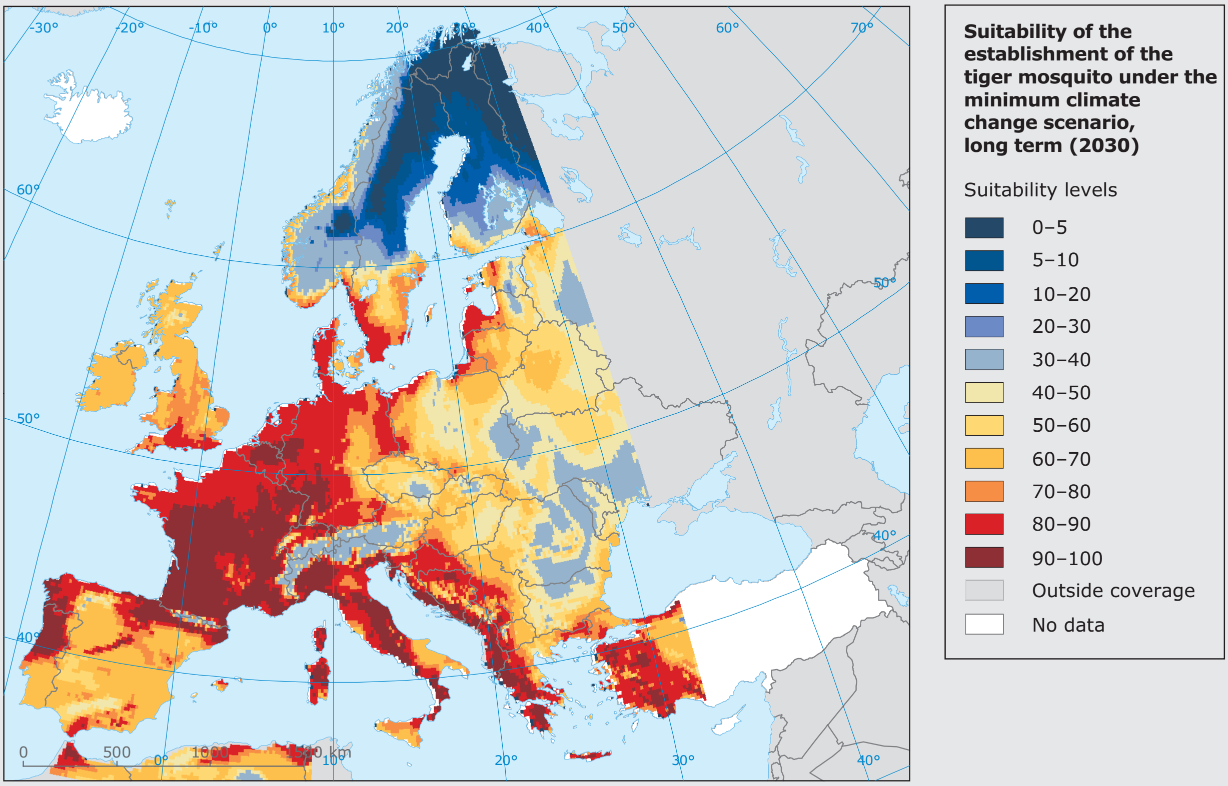
Climate change may also exacerbate existing environmental problems, such as particulate emissions and high ozone concentrations, and pose additional challenges to providing sustainable water and sanitation services. Climate-related changes in air quality and pollen distribution are expected to affect several respiratory diseases. Ageing water treatment and drinking water supply systems are particularly susceptible to weather extremes, with potential impacts on the spread of water-borne diseases. Systematic assessment of the resilience of water supply and sanitation systems to

([13]) Diseases transmitted by the bite of infected arthropod species, such as mosquitoes, ticks and sandflies.

Box 2.2 Chikungunya fever

The tiger mosquito, a vector of several viruses including chikungunya (CHIKV), has extended its range in Europe over the past 15 years and is projected to increase it even further. The first confirmed outbreak of chikungunya fever in Europe was reported in the Emilia-Romagna, Italy in August 2007 (ECDC, 2009). While this episode was accidental, and not related to climate change, climatic models indicate the potential for further transmission and dispersion of the vector under favourable climatic conditions. The first risk maps for Europe indicate suitability for establishment of the mosquito under several short-term (2010) or long-term (2030) scenarios. When interpreting and using such maps, careful consideration needs to be given to the existing uncertainties, as well as other conditions affecting the possible spread of disease.

Map 2.10 Suitability of the establishment of the tiger mosquito under the minimum climate change scenario, long term (2030)



Note: Colours indicate the suitability levels, from dark blue (less suitable areas) to dark red (most suitable areas).

Source: Adapted from 'Prospective impact of climate change on *Aedes albopictus* distribution in Europe: minimal impact, long-term change scenario' in ECDC Technical Report 'Development of *Aedes albopictus* risk maps'. European Centre for Disease Prevention and Control (ECDC), 2009.

climate change and inclusion of its impacts in water safety plans are needed (WHO, 2010b).

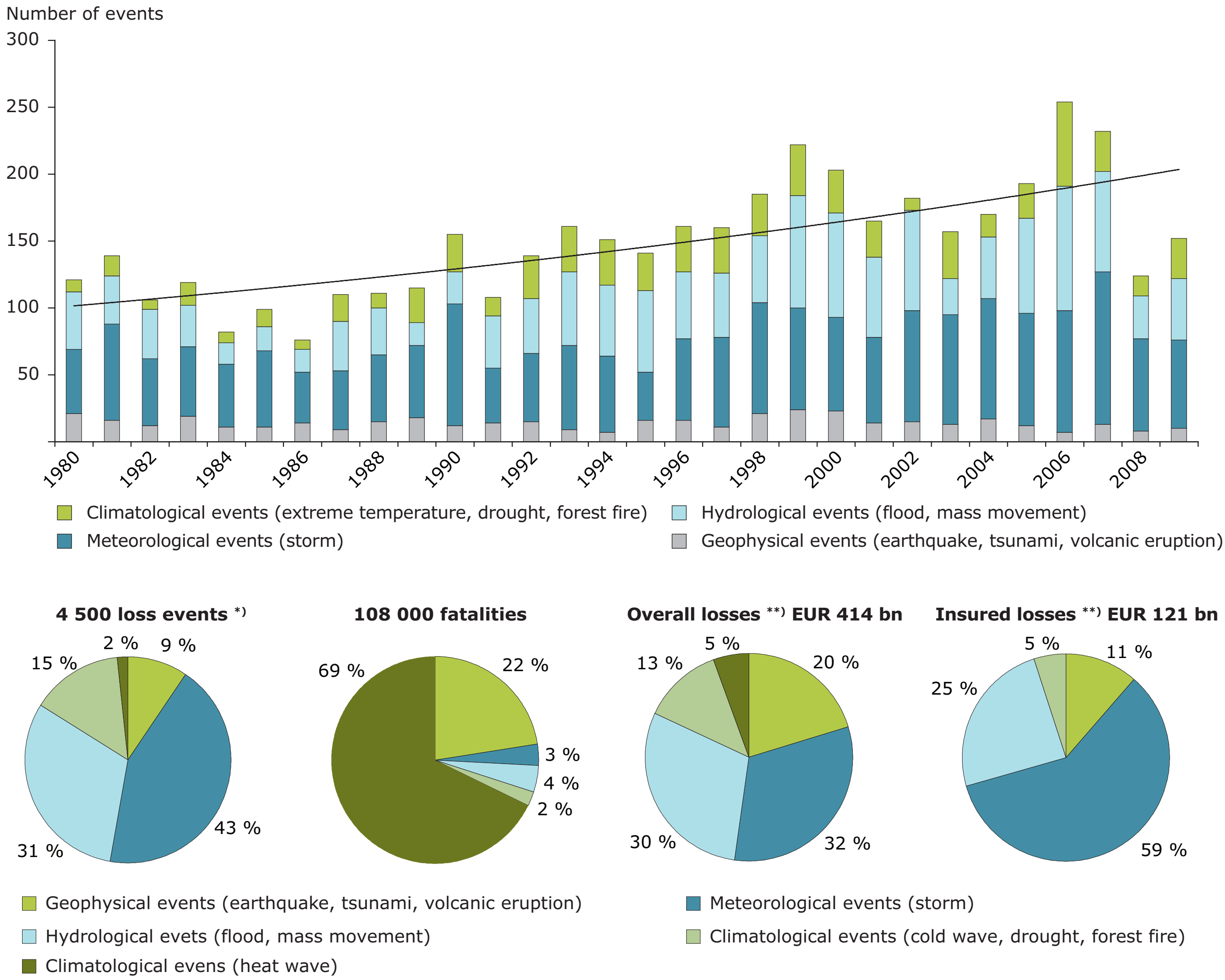
2.7 Damage costs

Economic losses from weather and climate-related events

According to the NatCatSERVICE of Munich Re, the number of disasters in EEA member countries shows an upward trend since 1980 (see Figure 2.4). Whereas the number and impacts of weather and climate-related events increased considerably between 1998 and 2009, the number of geophysical hazards appeared to remain more stable.

According to Munich Re, hydro-meteorological hazards account for about 90 % of natural disasters that have occurred in Europe since 1980 and around 81 % of the economic losses (Munich Re, 2010). Its NatCatSERVICE reports an increasing trend of overall average economic losses by weather events from EUR 5 billion in 1980 to more than EUR 7 billion in 2009 (2009 prices).

Figure 2.4 Natural disasters in EEA member countries, 1980–2009



Note: * Definition loss events: Events can occur in several countries; events are counted countrywise; ** In 2009 values.

Source: NatCatSERVICE, as of August 2010 (Munich Re, 2010).

Between 1998 and 2009, the economic toll of natural disasters in the whole of Europe approached EUR 118 billion (Munich Re, 2009) ([14]). About half of all losses can be attributed to a few large events such as storms Lothar in 1999 and Kyrill in 2007, and the floods of Central Europe in 2002 and in the United Kingdom in 2007. Two thirds of economic losses by natural disasters between 1998 and 2009 were caused by floods and storms, as these tend to affect large areas.

One important question is to what extent the observed increase in overall losses during recent decades is attributable to changing climatic conditions rather than other factors. Available studies, such as Barredo (2009; 2010) on river floods and storms, suggest that increased losses are primarily due to socio-economic changes and increasing exposure due to changes in population and economic wealth, and activities in hazard-prone areas. Upward trends in losses can also be explained to a certain

([14]) This corresponds to events that have been entered into Munich Re database for the whole of Europe, i.e. events that led to property losses and/or fatalities. The following Munich Re definitions apply to natural disasters: (1) A small scale loss event is defined as a 1–9 fatalities event with a small scale property damage; (2) A moderate loss event is defined as 10+ fatalities event with a moderate property and structural damage; (3) A severe catastrophe is defined as a 20+ fatalities event with overall losses in excess of USD 50 million; (4) A major catastrophe is defined as a 100+ fatalities event with overall losses in excess of USD 200 million; (5) A devastating catastrophe is defined as a 500+ fatalities event with overall losses in excess of USD 600 million; (6) A great natural catastrophe or great disaster is defined at leading to thousands of fatalities with the economy being severely affected and extreme insured losses; interregional or international assistance is necessary, hundreds of thousands are made homeless (UN definition).

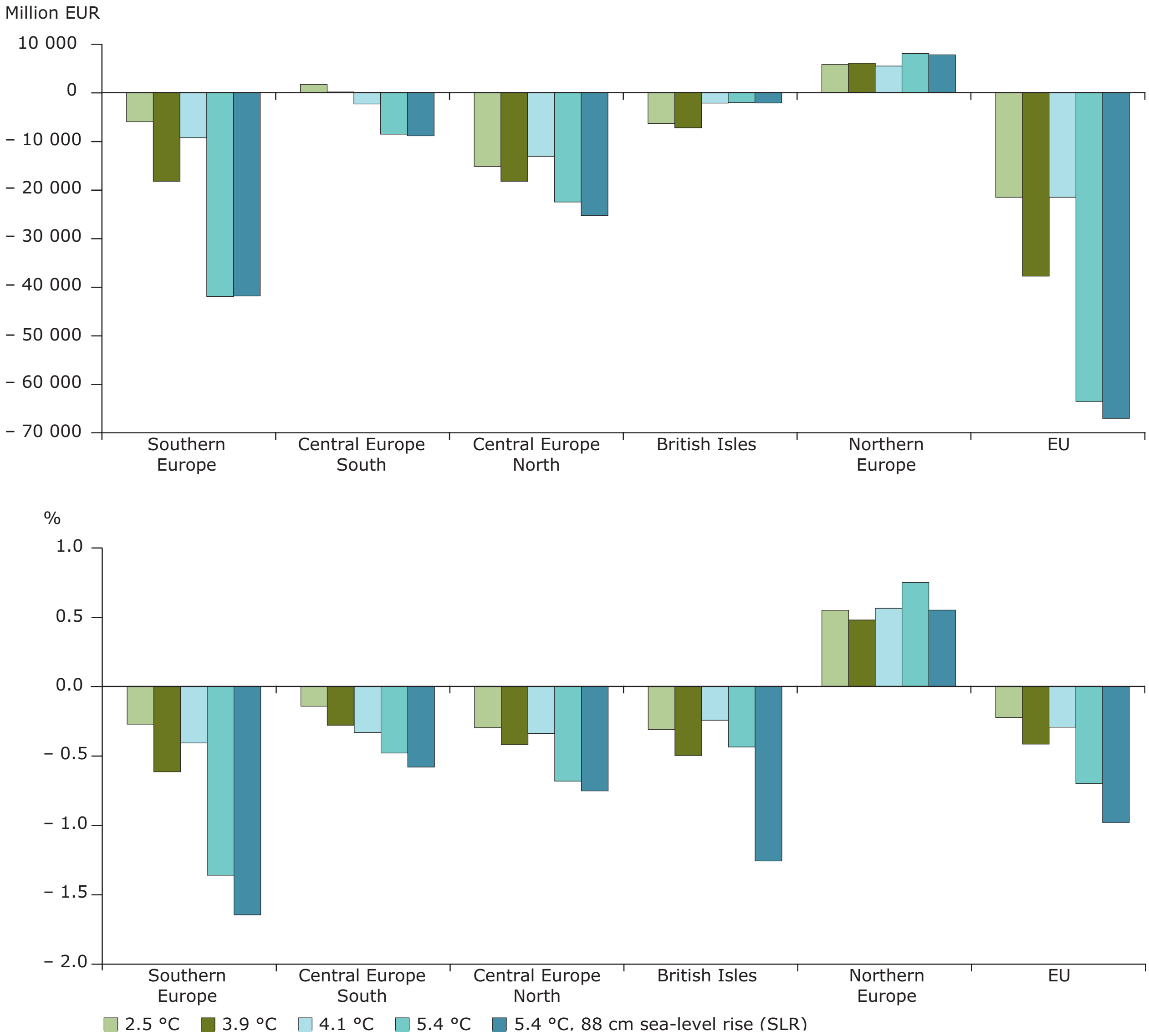
extent by better reporting. Although it is currently difficult to determine accurately the proportion of losses that are attributable to climate change (EEA-JRC-WHO, 2008), in view of current and projected climate change impacts its contribution to losses is expected to increase.

Integrated economic assessment

The PESETA study undertook an integrated economic assessment aimed at a better understanding of the geographical and sectoral patterns of the physical and economic effects of climate change in Europe (Ciscar et al., 2009). It considered the impacts and vulnerabilities of climate change in agriculture, river basins, coastal systems, tourism and human health for four different climate-change scenarios. As other key issues, such as effects on forestry, ecosystems and biodiversity or catastrophic events, have not yet been analysed, the PESETA project only provides an initial integrated assessment of the cost of damage.

Without public adaptation to climate change and if the projected climate of the 2080s were to occur today, the annual damage to the EU economy in terms of GDP losses due to climate change — mainly supply side effects — are estimated to be between EUR 20 billion for the 2.5 °C scenario and EUR 65 billion for the 5.4 °C scenario (see Figure 2.5). Damage would occur mainly in Southern Europe and the northern part of Central Europe. The EU annual welfare loss (i.e. households perspective and demand side effects) is estimated at between 0.2 % and 1 %.

Figure 2.5 Annual damage in terms of GDP loss (million EUR) and welfare change (%)



Source: Ciscar et al., 2009.

The estimated aggregated damages in PESETA are lower than in other studies because the coverage of market impacts is narrower and the non-market components of the damages are not taken into account. Thus, for instance, Fankhauser and Tol (1996) estimate the overall GDP loss for the EU at 1.4 %, under a scenario doubling the CO_2-equivalent concentration to 550 ppmv compared to pre-industrial levels. The PESETA 5.4 °C scenario with high sea-level rise (SLR), which would lead to a concentration level of 710 ppmv, has an estimated annual GDP and welfare loss of 0.5 % and 1 %, respectively.

The aggregated impact estimates mask large sectoral and regional variability (Figure 2.6). For example, under the 5.4 °C scenario with high SLR, most losses occur because of production losses in agriculture, damage to residential buildings from river floods and, particularly, damage to coastal systems and migration as a result of sea floods.

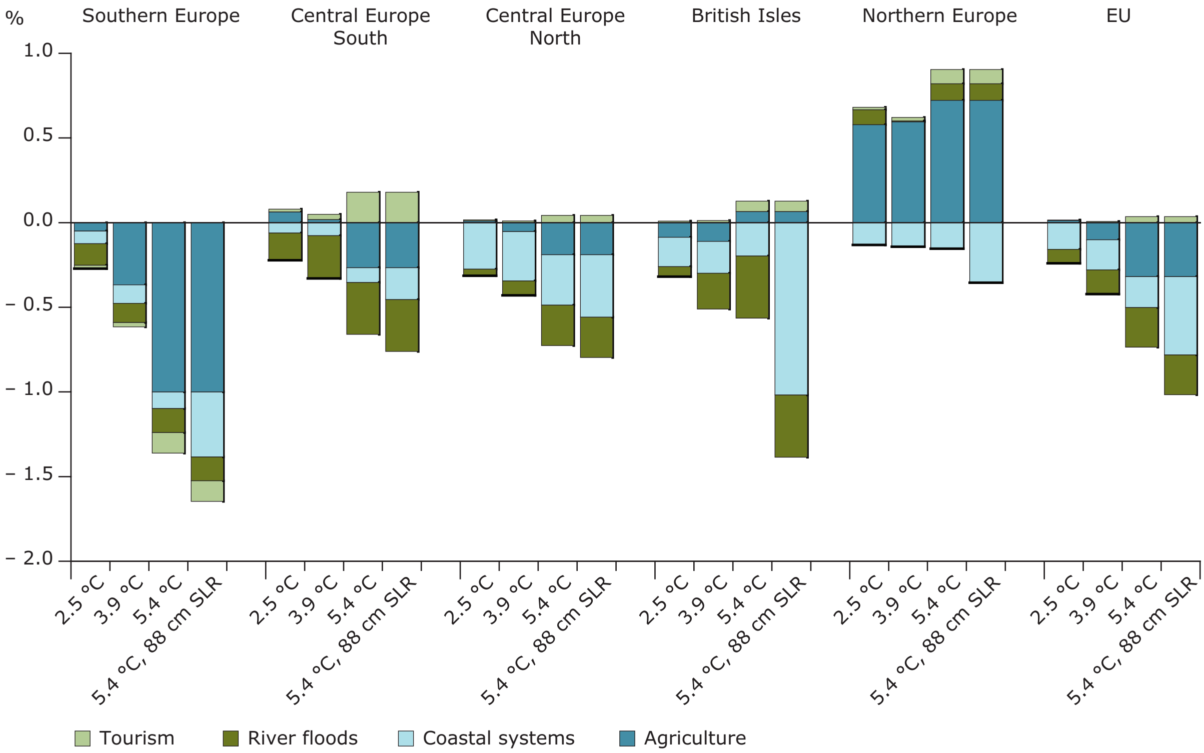
The southern European area is the region with highest welfare losses, ranging between 0.3 % and 1.6 %. Welfare in this region deteriorates steeply in the scenario with the highest temperature increase. Impacts in all sectors are negative and damage to agriculture is the most important one in relative terms, while tourism revenues could diminish by up to EUR 5 billion per year.

Welfare losses in the southern part of central Europe range between 0.1 % and 0.6 %, due mainly to damage from river floods. Agriculture would be negatively affected under the highest emission scenario while tourism would benefit. The northern part of central Europe would experience welfare losses between 0.3 % and 0.7 %, primarily due to damage to coastal systems. Economic costs of river floods could reach EUR 5 billion per year and tourism sector could benefit slightly from climate change.

The British Isles would be particularly impacted under the warmest scenario with the welfare loss being estimated at 1.3 %. This would be due to combined river floods and impacts to coastal systems. Impacts on tourism are estimated to be positive, with up to EUR 4.5 billion in additional revenues.

Northern Europe is the only EU area with welfare gains in all scenarios, due mainly to the large positive impacts on agriculture, fewer river floods damages and higher tourism revenues. However, damage to coastal systems could be significant.

Figure 2.6 Sectoral decomposition of regional welfare changes



Source: Ciscar et al., 2009.

3 Adaptation

3.1 Framing adaptation

Adaptation is defined by the IPCC as the *adjustment of natural or human systems to actual or expected climate change or its effects in order to moderate harm or exploit beneficial opportunities* (IPCC, 2007). Even if atmospheric GHG concentrations remained at 2000 levels, the temperature increase would be about a further 0.6 °C by the end of this century relative to 1980–1999 (IPCC, 2007). Climate change increases the vulnerability of European society to a wide range of impacts on human and natural systems, and dedicated adaptation is therefore necessary to address these unavoidable consequences by both reducing vulnerabilities and strengthening resilience.

Practical examples of adaptation measures include: early warning systems and vaccination campaigns for health and heat wave risks; water supply and demand management for drought and water scarcity risks; defences, including beach nourishment for coastal and river flood risks; disaster risk management; land-use management and crop diversification; economic diversification and insurance; green infrastructure to enhance connectivity for plant and animal species; natural hazard monitoring; and reinforcing the built environment.

Adaptation responses can be clustered into the following broad categories:

- technological solutions — grey measures;
- ecosystem-based adaptation options — green measures;
- behavioural, managerial and policy approaches — soft measures.

Green and soft measures specifically aim at decreasing the sensitivity and increasing the adaptive capacity of human and natural systems, basically, building resilience (see Figure 3.1). They often provide low-cost solutions and we know enough for their implementation. High-tech and innovative technological solutions typically need funding and require more research, experience and training to be operated.

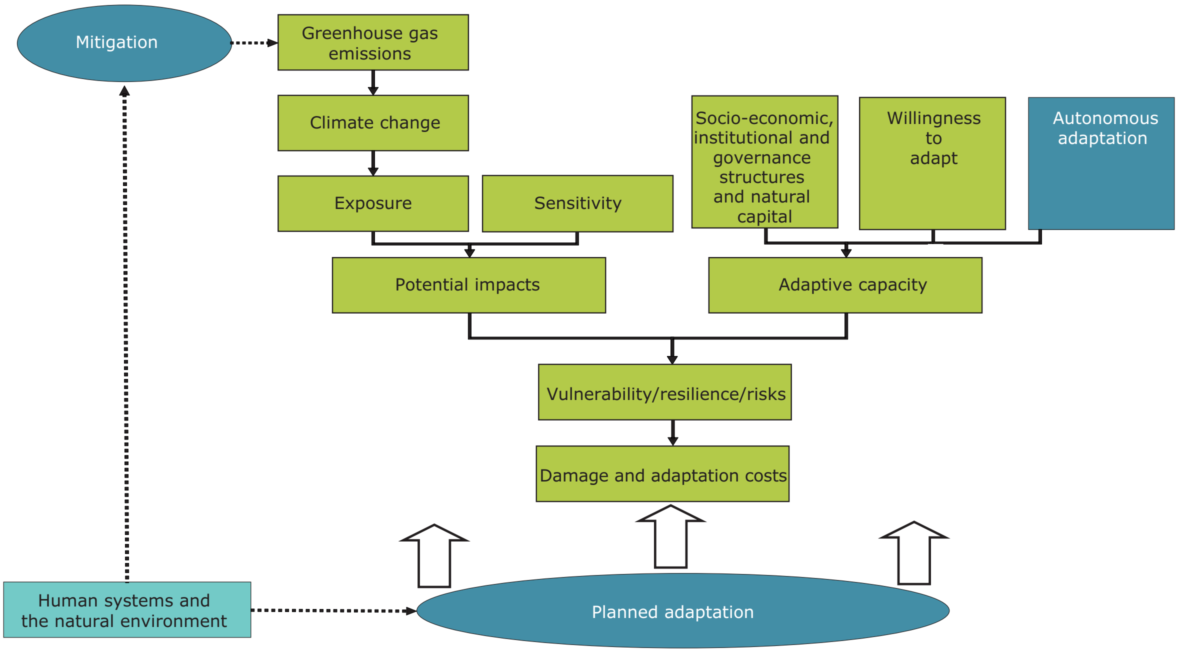
Furthermore there are various types of adaptation decision-making processes. Planned adaptation, which can be anticipatory/proactive or reactive, aims at taking measures to counteract expected impacts of climate change — before these are observed. They are the result of a deliberate decision, based on an awareness that conditions have changed or are about to change and that action is required to return to, maintain, or achieve a desired state. Autonomous adaptation is a reactive response to a variety of factors and is triggered by changes in natural and human systems, including the climatic stimuli and market forces. The focus here is mainly on planned adaptation, even though it is challenging in practice to disentangle and systematically distinguish the various types of adaptation, since planned adaptation packages may also facilitate autonomous adaptation.

Adverse and beneficial impacts of climate change have rather different implications for current policies because effective adaptation needs to consider all possible climate conditions during the horizon of a policy decision (e.g. the lifetime of infrastructure). If climatic risks are projected to increase in the future, this increase needs to be taken into account proactively in today's decisions in order to avoid adverse impacts on human lives, health, and welfare and/or costly retrofitting. In contrast, if climatic risks are projected to decrease, today's decisions would be unaffected because policies or infrastructure established today would still be able to manage the current level of risks. Potential savings (e.g. reduced efforts to manage climatic risks that have become obsolete) can only be realized reactively after the change in climate has manifested.

Adaptation initiatives should pay particular attention to no-regret measures that would be justified under all plausible future scenarios. No-regret measures typically involve over-specifying components in new build or refurbishment projects, for example, higher building insulation standards.

There is also a need to better understand mal-adaptation, which occurs when adaptation measures do not increase resilience/adaptive capacity or reduce vulnerability, for example inappropriate, not proportionate or cost-ineffective solutions; are environmentally unsustainable; or conflict with other long term policy objectives, for example, artificial snow making or air conditioning that conflict with mitigation targets (EEA, 2009; IPCC, 2007; UNDP, 2009). To avoid mal-adaptation both climatic and socio-economic factors of vulnerabilities have to be considered when developing policy responses.

Figure 3.1 Conceptual framework for climate change impacts, vulnerability, disaster risks and adaptation options



Source: Isoard, 2010; IPCC, 2007; Füssel and Klein, 2006.

Climate change adaptation is closely linked to the concept of disaster risk reduction (DRR) that aims to reduce the impacts of natural and technical hazards that could lead to a disaster. As adaptation and DRR share the same ultimate goal, reducing vulnerability to hazardous events (IPCC, 2009), vulnerability and disaster risk assessments are core issues to be addressed under both frameworks (Birkmann et al., 2009). There are also mutual co-benefits and synergies as adaptation can be integrated with various phases of DRR while adaptation to current weather extremes could increase resilience to climate change (IPCC, 2007).

It is important to identify and assess determinants of successful or unsuccessful adaptation in order to better inform policymakers about good practices. Regional case studies taken from a recent EEA report on adaptation to climate change and water-related issues in the Alps (EEA, 2009) provide valuable insights into the forces that promote or obstruct good adaptation practices. They specifically provide guidance on generic success factors for and barriers to good adaptation practices, recognising that regional specificities such as impacts and affected sectors, political and socio-economic contexts, cultures and values, land uses, social networks are key elements to consider. They also highlight that the successful transfer of lessons learned to other regions is far from straightforward.

Political support is key in initiating, driving and coordinating adaptation to climate change, providing a strategic framework for effective action. Once initiated, adaptation measures rely on a broad variety of factors for their success, relating primarily to institutional and governance structures, as well as organisational settings. For example, a sound legal framework is a crucial complement to political support; 'soft' adaptation actions on demand-side management usefully complement technological measures; involving/empowering stakeholders and raising awareness are vital especially in sectors with long planning horizons and lead times for implementing change; and monitoring progress and conducting integrated assessments of impacts, vulnerabilities and adaptation support regular reviews of policy objectives.

Barriers to adaptation typically include limited scientific knowledge and uncertainty about the local impacts of future climate change, and the lack of long-term planning strategies, coordination and use of management tools that consider climate change at regional, river basin and cross-sectoral levels.

3.2 Policy frameworks

International level

At the global level, many human and natural systems are highly vulnerable to even modest levels of climate change, with poor nations and communities, ecosystem functions and biodiversity particularly at risk. In line with its external policy, the EU is committed to supporting developing countries in adapting to climate change within the United Nations Framework Convention on Climate Change (UNFCCC).

Climate change adaptation has been recognised as one of the five key building blocks — together with mitigation, technology, finance and a shared vision — within the UNFCCC negotiations for the post-2012 period and is a vital element of any international climate change agreement (UNFCCC, 2010a). Many least-developed countries (LDC) and small island developing states (SIDS) are particularly vulnerable to climate change, and have limited adaptive capacity. The UNFCCC Copenhagen Accord of December 2009 recognises the need for enhanced action on adaptation to reduce vulnerability and build resilience in the most vulnerable developing countries and outlined a Fast Start programme funded by USD 30 billion for 2010–2012 and long-term finance of USD 100 billion annually by 2020 as the main elements of developed countries' financial commitments to both adaptation and mitigation (UNFCCC, 2010b). The EU (European Council, 10–11 December 2009) confirmed its readiness to contribute with Fast-Start funding of EUR 2.4 billion annually for the years 2010–2012, recognised the need for a significant increase in public and private financial flows to 2020 and reiterated its commitment to provide its fair share of international public support.

The EU supported the UNFCCC's Nairobi work programme (2005–2010) and the process of national adaptation programmes of action (NAPAs). The Nairobi work programme has been adopted to help countries improve their understanding and assessment of the impacts of and vulnerability to climate change, and to make informed decisions on adaptation measures and actions. NAPAs have been prepared and reported to UNFCCC by many developing countries, which provide an important way of identifying priority activities and urgent national adaptation needs.

In addition the United Nations International Strategy for Disaster Reduction (UNISDR) aims to build disaster-resilient communities by promoting increased awareness of the importance of disaster reduction as an integral component of sustainable development, with the goal of reducing human, social, economic and environmental losses due to natural hazards and related technological and environmental disasters. The EU supports the need to harmonise existing institutional and governance arrangements for DRR and climate-change adaptation. A contribution to that will be provided by the special report on managing the risks of extreme events and disasters currently being prepared by an expert group of IPCC (UNISDR, 2009a).

The inclusion of climate change in today's risk and vulnerability assessments also corresponds to a recommendation made within the Hyogo Framework of Action (HFA) adopted in 2005 (UNISDR, 2010; PreventionWeb, 2010a), *inter alia* by many EU Member States, which sets a global plan for disaster risk reduction that aims at substantially reducing disaster losses by 2015 in terms of lives and the social, economic, and environmental assets of communities and countries.

There is also recognition that there may be an increasing number of environmentally-induced migrants in future, who will have to leave their homes to find viable livelihoods and safety elsewhere. People often migrate for a combination of reasons, including armed conflicts, which make the expected number of persons displaced due to climate change very difficult to estimate. The climate change-related migration and displacement of people can have various drivers, including sudden disasters and slow-onset hazard events, permanent losses of territory, violence over shrinking natural resources and threats to public health. Most environmentally-induced migrants will probably remain, elsewhere, in their own countries, but others will cross international borders. Experts expect an amplification of the already established migration routes from sub-Saharan Africa to the Mediterranean, the Middle East and Europe over the coming decades. The United Nations Refugee Agency (UNHCR) estimates that, worldwide, there are between 25 and 50 million environmentally-induced migrants today and that there will be almost 700 million by 2050, while the UNFCCC secretariat refers to 50 million in 2010.

The EU's approach

The EU has adopted a Green Paper on Adaptation (EC, 2007a) followed by a White Paper (EC, 2009a). The Adaptation White Paper supports the preparation of a comprehensive adaptation strategy at the EU level in Phase 1, 2009–2012, which then shall be implemented as of 2013 in Phase 2. The key rationale for a need to take action on climate change adaptation at the EU level can be summarised as follows:

- many climate change impacts and adaptation measures have cross-border dimensions;
- climate impacts and adaptation affect single market and common policies;
- climate change vulnerabilities and adaptation trigger a new framework for solidarity;
- EU programmes could complement Member State resources for adaptation;
- potential economies of scale can be significant for capacity-building, research, information and data gathering and knowledge transfer.

The White Paper is framed to complement and ensure synergies with actions by Member States and focus on four pillars to reduce the EU's vulnerability and improve its resilience:

- develop and improve the knowledge base at regional level on climate change impacts, vulnerabilities mapping, costs and benefits of adaptation measures to inform policies at all levels of decision-making;
- integrate adaptation into EU policies;
- use a combination of policy instruments — market-based instruments, guidelines, and public-private partnerships — to ensure effective delivery of adaptation;
- work in partnership with the Member States and strengthen international co-operation on adaptation by mainstreaming adaptation into the EU's external policies.

The EU aims at an integrated approach with top-down policy strategies for mainstreaming adaptation into sectoral policies together with bottom-up activities building adaptive capacity and implementing actions. The pillars of action support adaptation initiatives at all levels of decision-making across sectors. Concrete initiatives have started to integrate adaptation into EU sectoral policies (Pillar 2), in particular with water and flood risk management, agriculture and rural development, health, and nature protection and biodiversity. The European Commission (DG CLIMA in the lead) is preparing for 2011 a Communication on Mainstreaming adaptation and mitigation.

The Water Framework Directive establishes a legal framework to protect and restore clean water across Europe by 2015 and ensure the long-term sustainable use of water. The 1st River Basin Management Plans for 2009–2015, which should since December 2009 be available in all River Basin Districts across the EU, take into account the impacts of climate change. In addition, climate change must also be properly integrated in the implementation of the Floods Directive. There are, however, serious delays in some parts of the EU — in several countries as of June 2010 consultations are still continuing — or river basin management plans have not yet been established.

Water directors of EU Member States issued a Common Implementation Strategy (CIS) guidance document (EC, 2009b) that addresses the integration of climate change impacts and adaptation in the implementation of the Water Framework Directive, the Floods Directive and the Strategy on Water Scarcity and Droughts, particularly in view of Member States' 2nd (2015) and 3rd (2021) river basin management plans. The EEA contributed to the EC's guidance document and is currently working on examples of good practices for the integration of climate change adaptation into water management. The United Nations Economic Commission for Europe (UNECE) (through its Water Convention) also released guidance on water and adaptation to climate change, particularly in connection with developing adaptation strategies and cooperation in transboundary basins (UNECE, 2009). Reviews of the Water Framework and Floods Directives, foreseen for 2012, will provide an opportunity to assess how climate change should be further integrated into EU water policies.

To address water scarcity, the EC will assess the need to further regulate the standards of water-using equipment and water performance in agriculture, households and buildings. When reviewing the implementation of the Water Scarcity and Droughts Strategy in 2012, options for boosting the water storage capacity of ecosystems to increase drought resilience and reduce flood risks will be evaluated.

The forthcoming Common Agricultural Policy reform and the new rural development policy plan (Pillar 2) will specifically take adaptation into account with, for example, requirements for more efficient water consumption.

By 2011 adaptation to climate change should also become part of the EU health strategy through the development of guidelines. The Adaptation White Paper included a dedicated Staff working document on 'Human, animal and plant health impacts of climate change' and DG SANCO has established a task force to implement it. In addition the European Centre for Disease Prevention and Control developed a handbook for national vulnerability, impact and adaptation assessments that addresses specifically climate change and communicable diseases in the EU Member States (ECDC, 2010). WHO Europe works to identify policy options to help prevent, prepare for and respond to the health effects of climate change, and its products include various guidance documents (WHO-Europe, 2010c). The Parma Ministerial conference in March 2010 also adopted a European Regional Framework for Action (WHO-Europe, 2010a).

The impacts of climate change must also be factored into the management of the Natura 2000 network and Habitats Directives to ensure the diversity and connectivity of natural areas and allow species migration and survival when climate conditions change. The EC has developed a Discussion Paper (EC, 2009c) within the EU Ad Hoc Expert Working Group on Biodiversity and Climate Change which showcases the links and interdependency between biodiversity and ecosystems, ecosystem services and climate change. Ecosystem-based adaptation measures have the potential to lead to win-win situations as they both provide adequate responses to climate change challenges and sustain ecosystems functions in the long term. In 2010 the EC also published a Communication that sets out possible future options for a long-term (2050) EU vision on biodiversity policy and mid-term (2020) targets beyond 2010 (EC, 2010a), also addressing climate change, and is planning to further address green infrastructure in

2011. The United Nations Convention on Biological Diversity (CBD) and UNFCCC have set up an experts group addressing the issues from a global perspective and formulating recommendations. The links and dependencies between solving the climate change and biodiversity loss challenges are at the heart of developing complementary policies that simultaneously promote biodiversity conservation and support climate-change mitigation and adaptation objectives.

In 2010, the EC also launched a Green Paper to open the debate on options for an EU approach to forest protection and information systems in the framework of the EU Forest Action Plan, as announced by the Adaptation White Paper (EC, 2010c). The Green Paper sets out the main challenges facing Europe's forests, reviews existing forest information systems and the tools available to protect forests, and raises a series of questions relevant to the development of future policy options.

The European Commission undertook a study in 2009 on the design of guidelines for the elaboration of regional climate change adaptations strategies that highlights, amongst other issues, the importance of existing EU regional funding instruments for mainstreaming adaptation (EC, 2009d). In future, EU Structural Funds might constitute an essential instrument to support regions and cities in allocating adequate funds for mainstreaming climate change adaptation in building, water or energy policies. The establishment of adaptation strategies requires indeed strategic long-term decisions and funding opportunities to efficiently adjust management practices. The ESPACE project also addressed governance issues by stressing the importance of adaptive management structures, and combining change and risk management approaches for integrating adaptation into spatial planning (ESPACE, 2007). In this context mainstreaming adaptation also refers to integrating climate change into instruments such as the Environmental Impact Assessment (EIA) and Strategic Environmental Assessment (SEA) and the related directives (EC, 2010b).

To improve information sharing and management, the Adaptation White Paper proposes to establish an EU Clearinghouse on climate change impacts, vulnerability and adaptation to maintain a wide range of information at European, national, regional and sectoral levels on climatology and impacts, vulnerability assessments, good adaptation practices and policy frameworks. It would also link to other similar or related initiatives such as the Biodiversity Information System for Europe (BISE)/European Community Biodiversity Clearing House Mechanism, the Water Information System for Europe (WISE) and the Global Monitoring for Environment and Security (GMES). Strengthening the knowledge base is further supported by numerous regionally-oriented adaptation EU projects, notably the EC's INTERREG and FP7 research programmes (see References).

Finally, various legislative initiatives on disaster risk reduction started recently, such as the Flood Directive, the Communication on Water Scarcity and Drought and the Communication *A Community approach on the prevention of natural and technological disasters*. This last proposes to focus action on developing knowledge-based prevention policies; linking actors and policies throughout the disaster management cycle and improving the effectiveness of existing financial and legislative instruments.

National and regional levels

The EEA keeps a regularly updated overview of progress towards the development and implementation of national adaptation strategies (NAS) online (EEA, 2010a). Eleven European countries — Denmark, Finland, France, Germany, Hungary, the Netherlands, Norway, Portugal, Spain, Sweden and the United Kingdom — have adopted NAS so far, while several others are expected to adopt such a strategy in the next few years — Austria by 2011, Belgium by 2012, Estonia, Ireland, Latvia and Switzerland by 2011. In addition countries have also submitted information on their adaptation plans in their 5th National Communication to the UNFCCC due on 1 January 2010. National audit offices are also increasingly involved in undertaking reviews of adaptation policies for national parliaments, and guidelines for auditing responses to climate change are being developed (NAO, 2009).

Adaptation initiatives are already being implemented through policies, investments and changes in behaviours, such as no-regret measures that are relevant under all plausible future scenarios. These have recently been reviewed and evaluated for some EU member states (Biesbroek et al., 2010; Swart et al., 2009a; IVM, 2009). Key findings from these studies show that in general countries are aware of the need to adapt to climate change. Nevertheless, compared to climate change mitigation, many are only at an early stage of developing policy frameworks. Many adaptation initiatives are not undertaken as stand-alone actions, but are embedded within broader sectoral measures, for example water-resource management and coastal defence strategies.

In many countries adaptation started with assessing needs, setting up research programmes to increase the knowledge base, identifying policy and financial instruments and fields of cooperation. The implementation of national adaptation strategies is only starting, due partly to the complexity in translating existing knowledge into policy packages. Developing implementation programmes is therefore a policy challenge in many countries in connection with plans for mainstreaming adaptation within existing policies and economic instruments and working out reporting/monitoring mechanisms. In addition only a small number of adaptation measures are found to explicitly consider scenarios of future climate change.

The integration of adaptation into sectoral policies is considered as crucial to avoid contradictions between policies and benefit from synergies, though the number of sectors included differs widely between countries. Some countries, especially in north-western and northern Europe, have also acknowledged possible positive impacts of climate change and defined policies to take advantage of them. There is also a strong need for communication tools that enhance information sharing, which differs greatly between countries, to address the lack of awareness about adaptation issues and the multi-dimensional aspect of the topic — multiple sectors, scales, regions, communities and stakeholders.

Country comparisons shows that many existing policies for coping with weather-related events already contribute to climate change adaptation in most countries, and that priority sectors differ widely due to historical, climatic and geographical circumstances. With regard to disaster risk reduction at the national level, one major activity has been the establishment of national strategies and national platforms for disaster risk reduction. So far, 11 European countries have established such a platform and many more have established official Hyogo Framework Focal Points (UNISDR, 2009b; PreventionWeb, 2010b).

Participative processes for developing NAS have mainly included ministries. Participation of other stakeholders, for example representatives of other decision-making levels, environmental and business NGOs, scientists, has so far been limited although it has been recognised as important.

Various factors that motivate, trigger and facilitate the development of adaptation policies have also been identified, as have a variety of weaknesses and threats that hinder the process (Biesbroek et al., 2010; Swart et al., 2009a) (see Table 3.1).

Various organisations or countries have developed tools and guidance for screening adaptation options to cope with events such as floods, droughts, heat-waves and sea-level rise, and setting priorities, such as the Adaptation Wizard (UKCIP), the Adaptation Decision Explorer (weADAPT) or the Digital Adaptation Compendium (EU ADAM project, 2009). A multi-criteria analysis is commonly used for assessing adaptation options. The Netherlands has developed a routeplanner to assess and rank adaptation options depending on criteria such as feasibility and cost-benefit considerations (Van Ierland et al., 2007), while in France, criteria for ranking sectoral options with a long-term planning horizon have been developed (Hallegate, 2009). The process of ranking adaptation options should involve appropriate stakeholders at the regional, national or sectoral level to reflect the specificities of the vulnerable region, sector or community, both in spatial and temporal terms.

Adaptation will to a large extent occur at a decentralised level, so the efficiency of individual adaptation measures depends on local conditions and the ability to take these into consideration. Regional and sub-national adaptation strategies and processes support this and offer solution-oriented and stakeholder-specific perspectives. Regions and municipalities are increasingly concerned about their vulnerability, and some have started developing and implementing their own adaptation strategies. At least 29 regional and local adaptation initiatives and strategies in the EU have recently been identified (Swart, 2009). Key sectors included are landscape and spatial planning, water, health and biodiversity. Andalucia, Spain; North-Rhine Westphalia, Germany (NRW, 2009); and Rhônes-Alpes, France have been the first regions to embark on developing and adopting regional adaptation strategies. Since 75 % of the European population lives in urban areas, some cities, including Barcelona, Copenhagen, London and

Table 3.1 Generic characteristics of several National Adaptation Strategies

	Contributing significantly to achieving the NAS objectives	Hindering the achievements of the NAS objectives
Related to historical conditions and institutional development of the NAS	**Strengths** Targeted adaptation research Planning for implementation, review and funding Coordinating between sectors	**Weaknesses** Lack of coordination between administrative levels Lack of stakeholder involvement Unclear division of responsibilities Lack of specialised knowledge Scientific uncertainties
Related to the current and future conditions and developments external to the NAS	**Opportunities** Development and export of knowledge Spillover of policy integration and multi-level governance for non-EU policies	**Threats** Cross-level conflicts Cross-sectoral conflicts Lack of resources Lack of public support/awareness Global impacts

Source: Biesbroek et al., 2010; Swart et al., 2009.

Rotterdam, have also started to develop adaptation plans and are getting increasingly organised (e.g. C40 Cities — Climate Leadership Group) to tackle this environmental and governance challenge (Rotterdam City, 2007; London City, 2010). Various trans-national initiatives and strategies also exist, such as the Action Plan on Climate Change of the Alpine Convention.

The objectives of these plans differ widely, ranging from increasing public awareness and reducing vulnerability to increasing coping capacity to extreme events, but the implementation of practical measures has so far been given little attention. However, the 2007 floods in the United Kingdom revealed that some of the most effective management measures may be taken by local authorities and individual households (Pitt, 2008).

3.3 Adaptation options

This section, which is not meant to be exhaustive, reviews a number of adaptation options and complements other thematic assessments, such as on water resources for example.

Coastal zones

A range of adaptation options is available for coastal management, including planning for rising sea-levels by the building or strengthening of coastal and river flood defences; protecting and strengthening natural defences such as dunes and other green infrastructure; land-use management, and moving back from the coast (Klein et al., 2001). The implementation of these options is often embedded in small-scale socio-institutional management and planning processes which are difficult to model or forecast.

In 2009, the EC addressed the economics of adaptation to climate change in EU coastal areas and provided insights from an empirical perspective into the state-of-play and financial dimension of the actions undertaken to prepare Europe's coastal zones and outermost regions for the effects of climate change. Specifically it identified adaptation options for sea-level rise, flooding and erosion — protect/accommodate/retreat versus hard/soft measures — highlighted the fact that the benefits of adaptation outweigh the costs many times over. It estimated that total cost of Europe's coastal protection could amount to EUR 15.8 billion for the period 1998–2015 and also found that 85 % of total coastal protection expenditure would be borne by five countries — Germany, Italy, the Netherlands, Spain and the United Kingdom.

Based on the DIVA model, Hinkel et al. (2009, 2010) also assessed the vulnerability of European coastal areas to sea-level rise and storm surges under the assumption of adaptation. Given the magnitude of potential impacts, it is rather unrealistic indeed to assume no adaptation in the medium and long term (see Section 2.2). The adaptation scenario considers adaptation options in the form of dike building and beach or shore nourishment.

Table 3.2 shows that adaptation reduces the number of people at risk of being flooded by a factor of 7–12 in 2050 and by a factor of 288–111 in 2100, under A2 and B1 scenarios respectively. The number of people at risk of being flooded per year decreases over the century even though sea levels are rising as dikes are assumed to be raised to a higher protection level as GDP increases, reflecting people's decreasing tolerance of risk with rising wealth. The countries most affected in 2100 under A2 are the Netherlands, with 700 people being affected by flooding, the United Kingdom and France, each with 600. Beach nourishment appears cost effective as land loss due to coastal erosion is estimated to be negligible.

In 2100 residual damage costs are roughly eight to nine times lower with adaptation than without and only

Table 3.2 People at risk of being flooded, land lost, damage and adaptation cost at EU-27 level with and without adaptation (SRES A2 and B1 scenarios)

	People at risk of being flooded (thousand/year)		Land eroded and lost (km²/year)		Adaptation cost (billion EUR/year)		(Residual) damage cost (billion EUR/year)		Total cost (billion EUR/year)	
	Without adaptation	With adaptation	Without adaptation	With adaptation	Without adaptation	With adaptation	Without adaptation	With adaptation	Without adaptation	With adaptation
A2										
2030	21	6	7	0	0	1.7	4.8	1.9	4.8	3.6
2050	35	5	10	0	0	2.3	6.5	2.0	6.5	4.2
2100	776	3	16	0	0	3.5	16.9	2.3	16.9	5.8
B1										
2030	20	4	6	0	0	1.6	5.7	1.6	5.7	3.2
2050	29	3	8	0	0	1.9	8.2	1.5	8.2	3.5
2100	205	2	12	0	0	2.6	17.5	1.9	17.5	4.5

Source: Hinkel et al., 2009, 2010.

increase slightly over the century. Adaptation costs amount EUR 3.5 billion per year under A2 in 2100 and EUR 2.6 billion per year under B1. The total costs are significantly lower than damage costs under the no adaptation scenarios, which is in accordance with the PESETA results and other previous studies (Ciscar et al., 2009; Richards and Nicholls, 2009; Richards et al., 2007; Tol et al., 2008) ([15]). Total costs are generally higher under A2 because the higher sea-level rise leads to higher salt intrusion ([16]) and sea flood damage as well as to higher beach nourishment costs. Overall these findings show that the adaptation options considered constitute a strategy that pays off many times over compared to inaction.

Germany has the highest adaptation cost in 2100 — estimated at EUR 619 million per year under A2, followed by the United Kingdom, Denmark, France and the Netherlands. On average, dike building and beach nourishment contribute roughly equal amounts to total adaptation costs in the EU-27, with sea dike raising having the greater contribution at the beginning of the century and beach nourishment at the end. The shift is caused by the rise in tourism as a result of population and economic growth, and climate change, implying that long sandy beaches become more valuable and worth protecting. Total residual damage and adaptation costs relative to national GDP are much smaller compared to the no adaptation scenarios and are the highest for Estonia under A2 at 0.16 % of GDP. For all other countries relative total costs do not exceed 0.06 % of GDP.

Rain-fed agriculture

Generic adaptation options include local collection and use of rain water provided that this does not disturb the natural supply to the different groundwater layers; increases in irrigation efficiency; expansion of irrigated and rain-fed cropland; imports of agricultural products; insurance and lifestyle changes (EC, 2007b).

Gerten (2009) assessed an adaptation scenario for rain-fed agriculture assuming that 25 % of soil evaporation from cropland during the growing period could be avoided through soil and water conservation strategies like mulching or different tillage systems and 25 % of all surface and subsurface runoff generated on rain-fed and irrigated cropland was harvested in cisterns, ponds and dikes, with the water being used later during dry spells when crops are water-limited. The scenario evaluates the potential increases in crop yields. The adaptation options considered require neither the installation of large-scale irrigation systems nor the expansion of irrigated or rain-fed cropland.

This adaptation scenario suggests possible crop production increases of more than 10 % over large parts of Europe (see Map 3.1). Productivity increases are small in northern latitudes and at high altitudes, because crop production in these regions is limited mainly by temperature and sun radiation rather than by water (Gerten et al., 2007). In individual regions such as south Europe, adaptation measures such as the ones considered here would however probably be insufficient to buffer climate change-induced dry spells and resulting drops in crop yields (Rost et al., 2009).

Cities

A key dimension of adaptation to climate change in cities is how to secure the functioning of essential infrastructure for energy provision, electricity and heating, water supply and wastewater collection and treatment, transport, health services, while avoiding the loss of biodiversity.

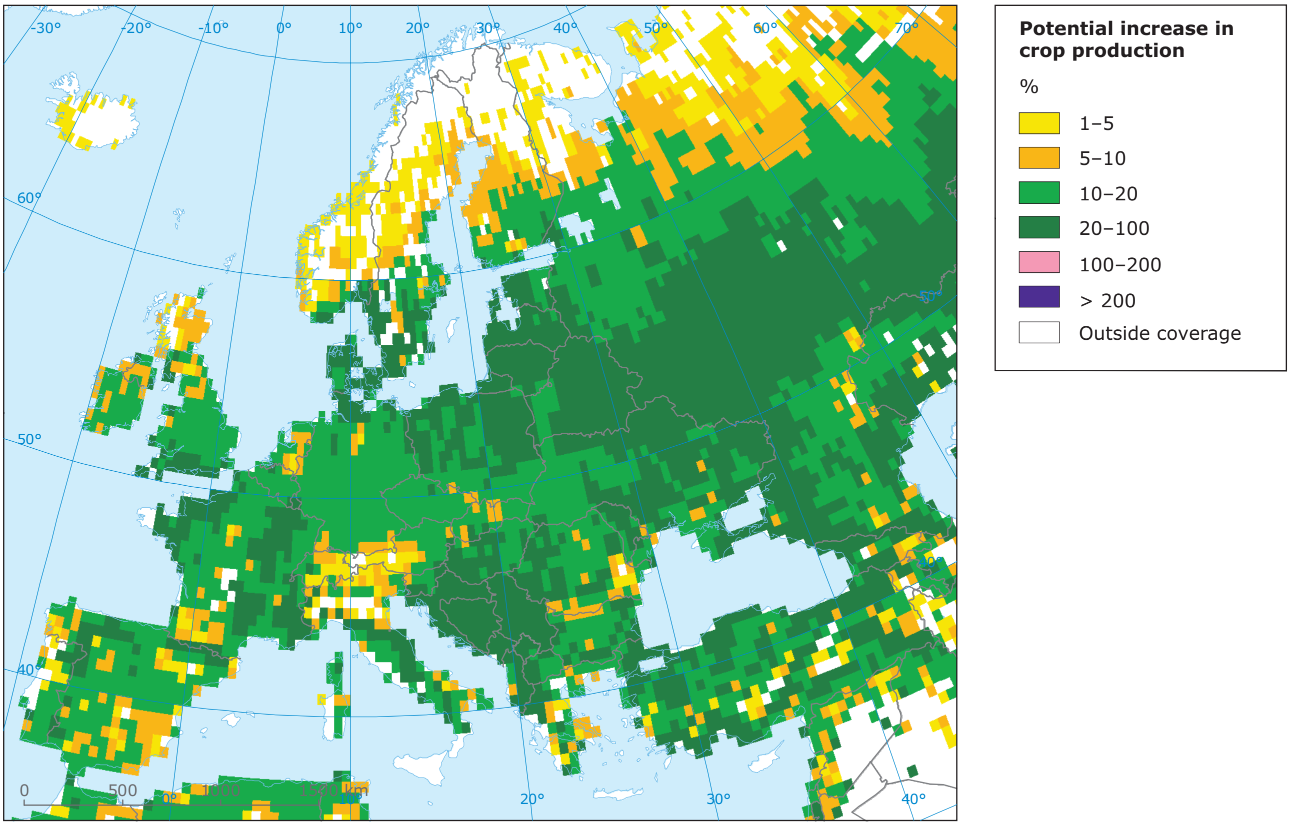
Cities vulnerable to drought or excessive rainfall need to act in tandem with their regions to increase water storage capacity, improve drainage systems and develop strategies for implementing more green roofs that both act as a buffer to heavy precipitation by limiting run-off and limit heat island effects. The bulk of socio-economic damage comes from rain-fed floods (Pitt, 2008), which are likely to become a major problem in many European urban areas, especially those experiencing a significant expansion of the built environment. Other cities will need to adapt to rising sea levels and associated risks of coastal and river flooding. Dikes and barriers are relevant options, together with other approaches such as in London, where the use of green spaces adjacent to the river Thames to store floodwater is being considered. In addition buildings will need to be cooled or heated more efficiently and those designed for cold harsh winters will need to function in drier and hotter climates. Also challenging is the construction of new buildings as their design needs to be highly flexible to gradually adjust to drastically different conditions over the coming decades.

Increasing green open space areas in cities — reducing the sealing of soil — reduces urban heat island effects. Public spaces may also need to be used differently, for example for cooling purposes. Adaptation in the health sector might include awareness raising and better treatment of vulnerable groups together with improved early-warning management systems.

([15]) A recent study carried out by the EC that compares the adaptation costs estimated in the PESETA project with empirical data on expenditure finds that the actual expenditure in Europe, amounting to EUR 1.07 billion in 2008, corresponds to the upper extent of the PESETA estimates (EC, 2009b).

([16]) Note that no adaptation options are considered for salt intrusion and that salt intrusion into coastal aquifers is not taken into account as the relevant data and models are not yet available at broad scales.

Map 3.1 Potential increase in crop production under the adaptation scenario



Note: 25 % of runoff from cropland collected and used during dry-spells (water harvesting) and 25 % of soil evaporation from cropland avoided to increase plant transpiration (vapour shift). Simulation done for recent climatic conditions (1971–2000 average) and distribution of cropland and crop types as of 2000. Based on the LPJmL vegetation and water balance model using the ensemble mean from 21 General Circulation Models (GCMs) that were part of the 4th IPCC Assessment (Randall et al., 2007).

Source: Gerten, 2009.

While cities acknowledge the need to rethink the nature of their urban fabric, specific action is still limited. Spatial planning, including ecosystem-based adaptation options such as multi-purpose use of green areas, is emerging as a key tool for implementing measures. Many adaptation solutions, whether technological, green or soft options, are available and could be implemented at a reasonable cost. In future, EU Structural Funds might constitute an essential instrument to support cities in allocating adequate funds for mainstreaming climate change adaptation in building, water or energy policies.

As European cities are not currently designed for climate change, this presents planners, developers, architects and urban designers with significant challenges, but also enormous opportunities to create innovative urban environments that will be attractive while functioning well as the climate changes (Shaw, 2007). Architects and developers must think creatively, to ensure that the built environment adapts to the changes ahead. An adapted and sustainable urban environment makes use of well-designed green and water (blue) spaces for cooling, storing water, and infiltration of rainfall.

It is important to recognise the relationship between large-scale strategic adaptation strategies at the conurbation scale such as networks of open spaces, and smaller-scale options including the orientation of individual buildings. Higher densities in urban areas will exacerbate some climatic risks including thermal discomfort, health and urban flash flooding, but these risks will also create opportunities by highlighting the need for high quality green spaces and the innovative use of urban form. Suburban areas characterised by lower densities offer more versatile spaces for developing adaptation solutions. Rural-urban fringes, where densities are likely to be low, provide space for large-scale strategies such as green space infrastructure and flood storage.

The case study presented in Figure 3.2 illustrates a menu of adaptation options to manage high temperatures using practical examples of action and techniques available at different spatial scales to increase adaptive capacity (Shaw, 2007). Climate change adaptation at the conurbation or catchment scale will potentially serve the whole city and is likely to include a variety of land uses. Opportunities for creating cost-effective and integrated solutions as part of an overarching climate change strategy may be greatest at this scale. The neighbourhood scale involves developments of discrete groups of dwellings, including a mix of uses, and can vary in size from an individual block to a large estate. Consideration will need to be given to adapting the public space between buildings and developments. At the building scale, smaller developments including individual dwellings, apartment blocks or commercial buildings provide opportunities for integrating climate change adaptation into or around buildings. Attention will need to be given to the design of the buildings, their surroundings, and how they are used and managed, in order to maximize current and future climate adaptation potential — design or building codes provide useful tools in this context. These certainly offer transferable lessons, but adaptation strategies will need to respond to local socio-economic circumstances and urban designs.

Eco-innovation

Adaptation takes time and requires an innovative mindset as well as innovative technology. The EU Environmental Technologies Action Plan in 2009 (ETAP, 2009) provided an updated review of potential adaptation mechanisms through eco-innovation and a set of formulations to enable the uptake of adaptation technologies including the more efficient use of scarce water resources and better spatial planning. Eco-innovation is defined as product, process or organisational innovations that contribute to the economic, environmental and social pillars of sustainability.

ETAP offers a forum for action already being taken at EU, national, regional and local levels to be presented and disseminated to a variety of stakeholders including businesses such as utilities and manufacturing industry, policy-makers at all levels of decision-making, the banking and insurance sector, environmental and business NGOs and the scientific community. Key lines of actions include the need not only to develop new technologies to enable adaptation to climate change but also to remove barriers to the exploitation of existing technologies.

Climate change will create opportunities for eco-innovation and new adaptation technologies that could further support local, regional, national and European economic activity. Adaptation and innovation policy frameworks need to be coordinated to provide the enabling conditions to foster the uptake of high- and low-tech adaptation options. Generally it appears that a suite of adaptation technologies or options — grey, green or soft — have been identified and are already available that can be implemented at affordable costs to respond to climate change. For example, Madrid architects have developed a futuristic air-tree that offers an opportunity for passers-by to cool down. But planting real trees also makes a genuine cooling difference and green surfaces can be 10 °C cooler than artificial ones. Infrastructural technologies also offer adaptation opportunities in cities that adequately take long-term spatial planning perspectives into account. Market signals to businesses, such as public procurement, also appear important for technology up-take, particularly for small and medium-sized enterprises. Synergies between adaptation and mitigation can also be found, for example, the prevention of soil erosion in land management can help avoid carbon release.

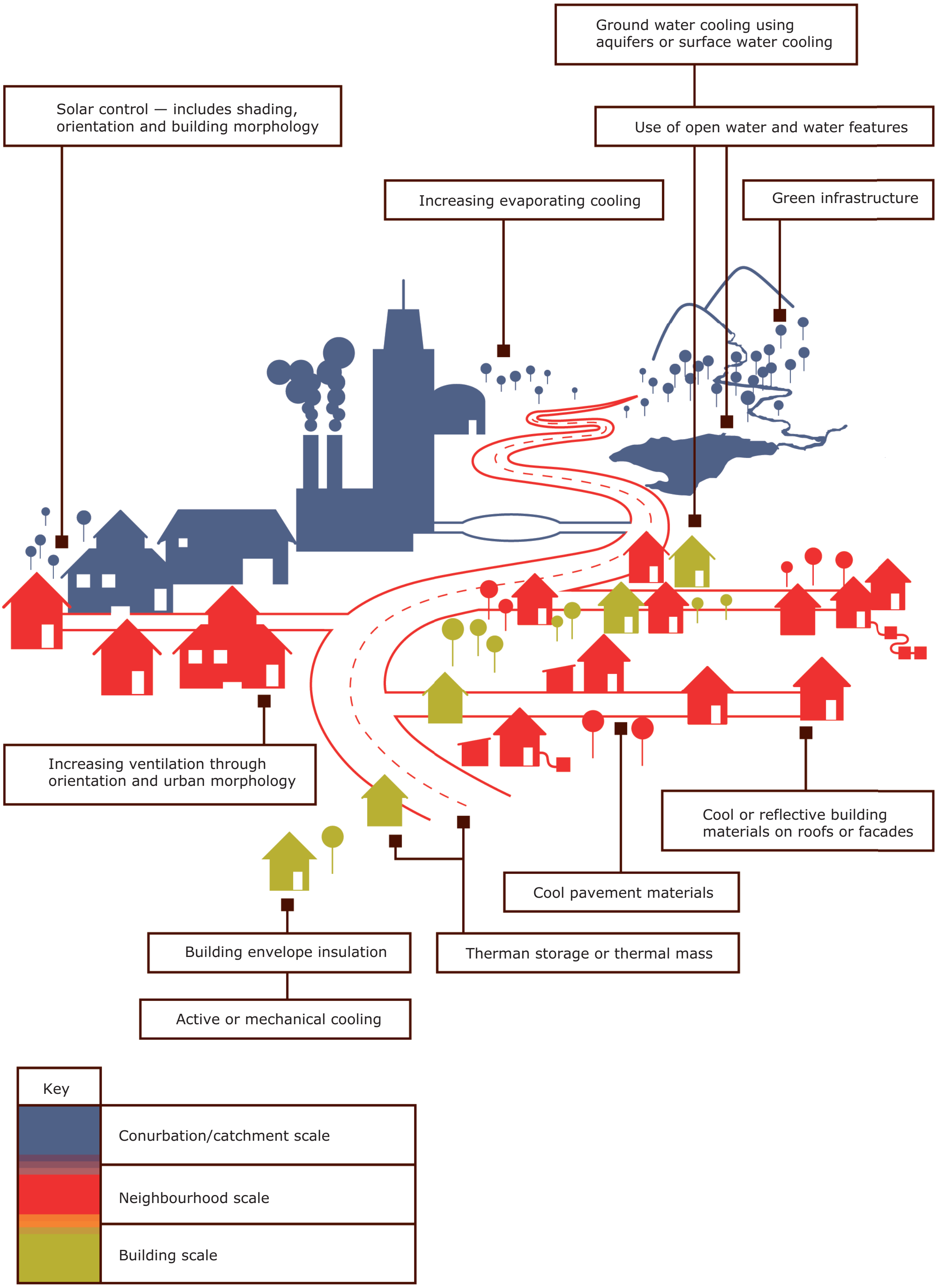
Urban planning has to be re-thought in terms of adaptation, particularly in regard to energy, transport, buildings, urban development and urban lifestyles — for example, improved rain-water management with a separation of sewage and rain-water drainage. Increases in soil sealing enhance both floods and the urban heat island effect. A potential adaptation option consists of improved control of water run-off through such innovations as rain-water harvesting, a vegetated landscape, infiltration devices, permeable and porous pavements, green roofs and reuse of water. Green roofs retain water, limit urban heat island effects, improve air quality and provide habitats to support wildlife. Many innovative solutions, including fast cropping vertical farms in cities or combined living, transport and other infrastructure applications are also being intensively studied as possible adaptation technologies.

Ecosystem-based approaches

Biodiversity and ecosystems provide multiple benefits and services to human society (see Box 2.1). Their conservation and sustainable use can contribute significantly to climate change adaptation coastal/estuarine ecosystems provide natural protection from storms and flooding; urban green space reduces the heat island effect, minimises flooding and improves air quality — and mitigation by conserving or enhancing carbon stocks. There is a compelling case for public investment in ecological/green infrastructure by, for example, conserving and restoring forests, wetlands and river basins, particularly because of its significant potential as a means of adapting to climate change (TEEB, 2009). However, insufficient attention is currently given to the integration of climate change and biodiversity actions and to fully exploiting this potential. The EU Ad Hoc Expert Working Group on Biodiversity and Climate Change has advocated a portfolio of tools to address this issue (EUAHEWBCC, 2009). These include:

- using ecosystem-based approaches to address climate change and biodiversity loss and ecosystem degradation in an integrated manner and to develop strategies that achieve mutually supportive outcomes;

Figure 3.2 Menu of strategies for managing high temperatures



Note: Courtesy of the TCPA. Graphic by thomas.matthews (www.thomasmatthews.com).

Source: Shaw, 2007.

- taking immediate steps to conserve and restore terrestrial and marine biodiversity and ecosystems, as these are the basis for cost-effective adaptation and mitigation actions and can provide multiple environmental and socio-economic benefits;
- engaging other sectors — for example, agriculture, the built environment, development policy, energy, finance, fisheries, forestry, health, regional planning, tourism, transport, water management — to maintain and increase ecosystem resilience and ensure that their activities do not further damage biodiversity and ecosystems;
- raising awareness of the links between climate change, biodiversity, ecosystems and their services through communication and education initiatives, making use of local knowledge and building institutional capacity and partnerships to facilitate integration;
- strengthening the knowledge base on climate change and biodiversity through increased research effort, and long-term monitoring and evaluation;
- addressing the economic significance of biodiversity and ecosystem services and their relevance to climate change adaptation and mitigation in reviews of financial measures and funding mechanisms.

Ecosystem-based adaptation uses biodiversity and ecosystem services in an overall adaptation strategy. It includes the sustainable management, conservation and restoration of ecosystems to provide services that help people adapt to the adverse effects of climate change (CBD, 2009a).

There are a number of examples of ecosystem-based approaches being implemented throughout Europe that not only contribute to climate change mitigation and adaptation, but also deliver benefits to the conservation of biodiversity and maintaining human health and well-being. Reducing deforestation, restoring wetlands and coastal/estuarine ecosystems, and providing more space for rivers can reduce flood risks. Forests stands are being diversified to reduce the impacts of storm events and outbreaks of pest species. Managed coastal realignment is being trialled to counter the effects of erosion associated with sea-level rise. And in the urban environment, tree cover is being increased to provide shade during heat waves and green space increased to reduce the risk of flooding during intense rainfall events (Cowan et al., 2010).

Forest management

European forests are relatively well managed but remain vulnerable to such threats as fragmentation, degradation and agricultural intensification. Climate change will pose additional threats and may cause losses of tree species or populations and changes in the composition of forest ecosystems. A series of options for active adaptation have been identified, including the regeneration, tending and thinning of stands; harvesting; forest management planning; forest protection; infrastructure and transport; nurseries and forest tree breeding; and further adaptation measures in risk management and policy (EC, 2008a; Lindner et al., 2010).

Tree populations have three biological adaptation options to avoid extinction in a rapidly changing climate: persistence through the inherent flexibility — plasticity — of tree species to withstand a wide range of environments; genetic adaptation to new conditions in existing locations; or survival through migration (Aitken et al., 2008). Climate change is likely to favour high levels of plasticity — low plasticity may lead to extinction — and at the forest ecosystem level, the coexistence of tree species with different plasticity levels can act as a buffer against changes (Rehfeldt et al., 2001).

In many parts of Europe, the rate of climate change is likely to exceed the adaptive capacity of many wild and domesticated plant species, including forest trees which have the highest levels of genetic diversity of any group of plants and have wide geographic and ecological ranges (Fujisaka et al., 2009).

In Europe, maintaining forest genetic diversity plays a crucial role in sustainable forest management and conservation of forest biodiversity by ensuring a continuous evolutionary process within tree populations and maintaining the resilience of forest ecosystems (Koskela et al., 2007). Widely distributed tree species in Europe are unlikely to face extinction at the species level due to climate change but some local populations are likely to decline, in particular at the margins of their distribution ranges. However, tree species with scattered and/or limited distribution are more vulnerable and may face serious threats also at a species level. Including genetic diversity considerations in practical forest management is a highly recommendable diversification and risk-reducing strategy that also benefits society at large by ensuring the supply of functions from forests. The way climate change will alter competition between trees and other living organisms — plants, insects, pests, fungi and bacterial diseases — may also have significant effects on the survival of tree species, forest habitats and biodiversity (EU 6th FP EcoChange project).

There is evidence that evolution in tree populations can occur over a few generations or less than 200 years, and local adaptation of tree populations can occur even in one generation (Kremer, 2007). Estimates of migration rates differ considerably among tree species but they are considered, on average, to be less than 100 metres per year (McLachlan et al., 2007). Aitken et al. (2008) estimated that migration rates of more than 1 000 metres per year are needed to respond to future climate change.

It is therefore unlikely that natural migration will be adequate to cope with rapid changing climate. Assisted migration is therefore needed, especially for tree species in fragmented landscapes and those with small population.

3.4 The cost of adaptation

Global level

Watkiss and Hunt (2010) ([17]) reviewed information on the costs and benefits of global adaptation, and highlight that assessments are extremely challenging since they involve very high aggregation and many simplifying assumptions ([18]). Therefore, even if all of the studies give broadly similar estimates of the costs of adaptation, they should be seen as only indicative and care must be taken in interpreting the apparent convergence of findings. The benefits of adaptation, although substantial, are found to be poorly covered explicitly in economic assessments.

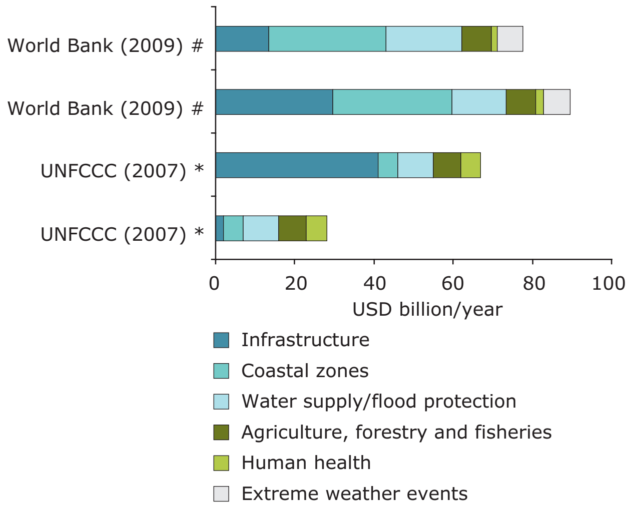
For developing countries, the aggregated studies indicate costs of adaptation of up to USD 100 billion/year for the year 2030 at current prices, EUR 85 billion/year ([19]). There are fewer aggregated studies for developed countries, but those that exist indicate estimates of costs of adaptation of up to USD 100–150 billion/year for 2030 (EUR 85–125 billion/year). These estimates indicate the costs of adaptation for Europe at very approximately USD 20 billion/year (EUR 16 billion/year). When added together, the studies indicate global adaptation costs of potentially several hundred billion EUR/year by 2030.

These studies have been the subject of a recent critical review (Parry et al., 2009) which highlights that they only capture a limited set of climate change effects for a small number of sectors, with biodiversity and ecosystem services generally omitted. All of them have been rapid scoping assessments and there has been little chance to validate the estimates against sector- and national-level analyses. Moreover, many of the studies use similar methods and have similar assumptions or constraints. The Parry et al. (2009) review considers that the estimates are therefore underestimates, perhaps by a factor of two or three for the sectors considered and potentially more than this when all sectors and all effects are considered.

Another suite of global studies, based on global economic integrated assessment models (IAMs), reports that adaptation is very effective, with high benefits when compared to costs. These models also report information on total adaptation costs, which in some instances are very similar to the aggregate estimates, but generally lower, at least in the short-term. There are also a growing number of regional and national studies due to report by the end of 2010. All of these will help build the evidence base and allow a more detailed and validated assessment of the likely order of magnitude of global adaptation costs and benefits.

Figure 3.3 shows the results from two of the most recent studies of the costs of adaptation in developing countries: the UNFCCC (2007) and World Bank (2009) studies. The UNFCCC study presents two alternative estimates, based

Figure 3.3 Comparison of the average annual costs of adaptation in developing countries



Note: Values shown are original study values, and have not been updated into equivalent price years.
World Bank shows cost of adaptation over period 2010–2050. The two values shown reflect the variation across the climate projections (from the underlying NCAR and CSIRO projections).
* UNFCCC shows cost of adaptation in the year 2030. A range of values is included for infrastructure based on a range of assumptions.

Source: UNFCCC (2009), based on UNFCCC (2007) and World Bank EACC (2009).

([17]) The Watkiss and Hunt (2010) review has benefited from the research work funded from the European Community's Seventh Framework Programme, as part of the ClimateCost Project (Full Costs of Climate Change, Grant Agreement 212774) www.climatecost.cc/. It has also benefited from the global and method review work undertaken as part of the UNFCCC technical paper on 'Potential costs and benefits of adaptation options: A review of existing literature' (www.unfccc.int).

([18]) Most of the studies reviewed focus on the short-term adaptation costs for the year 2030 and use a broadly similar approach to estimate values, based around investment and financial flow analysis; they typically consider how much it might cost to enhance the resilience of future investments or financial flows. The earliest studies estimated baseline future investment and the proportion of this that is sensitive to climate change, and then apply a possible mark-up, as a percentage, to estimate the additional funding needed to increase resilience. Later studies, such as UNFCCC (2007), adopt a more detailed analysis by sector and region. However, none of these earlier studies explicitly assess the benefits of adaptation. Most recently, the World Bank (2009) study adopted a different approach using climate projections.

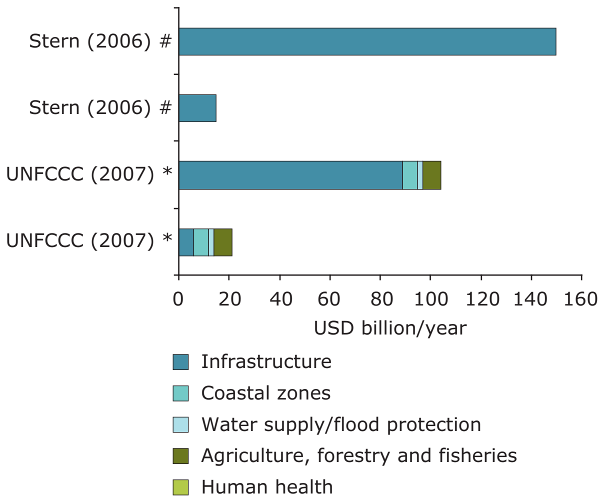
([19]) Exchange rate of USD/EUR as of June 2010.

on the range of estimates for the costs to the infrastructure sector. The World Bank study also presents two estimates, but these reflect the costs of adaptation in all sectors under a wetter and a drier climate scenario.

These studies have sectoral and regional breakdowns, which allow useful comparisons. The overall estimates of the two studies are similar, at least for the upper value, with costs of adaptation estimated at around USD 100 billion/year for the near-term (current prices; EUR 85 billion/year). The higher costs of the World Bank study arise mainly from the higher adaptation costs for coastal zones. However, as discussed, the review of Parry et al. (2009) considers that the estimates are significant under-estimates, potentially by a factor of two or three for the sectors considered and also highlights the omission of many other sectors — biodiversity and ecosystem services, industry etc — implying adaptation costs well in excess of USD 100 billion/year.

The UNFCCC study also presents values for developed countries, again with two alternative values reflecting the range of costs for the infrastructure sector. These are shown in Figure 3.4 and compared to the earlier values in the Stern Review on the Economics of Climate Change (2006), which also reports two alternative values for infrastructure, based on the percentage assumed to be at risk from climate change. While there is a wide range, the upper estimates are broadly similar, with the costs of adaptation estimated at up to USD 100–150 billion/year for the year 2030 (current prices; EUR 85–125 billion/year), dominated by infrastructure. Again, these estimates can only be considered as indicative, and only have a very low coverage of all the sectors at risk.

Figure 3.4 Comparison of the average annual costs of adaptation in developed countries



Note: Values shown are original study values, and have not been updated into equivalent price years.
Stern (2006) reports the cost of adaptation for moderate levels of warming (below 3 degrees).
A range of values is included for infrastructure depending on the percentage assumed to be at risk from climate change (0.05% or 0.5% of GDP) though specific time-scale is not specified.
* UNFCCC shows cost of adaptation in the year 2030. A range of values is included for infrastructure based on a range of assumptions.

Source: Compiled for this study based on UNFCCC (2007) and Stern (2006).

Under the UNFCCC there are currently four funding streams for financing developing countries — the Least Developed Countries Fund (LDCF), the Special Climate Change Fund (SCCF), the Global Environment Facility (GEF) Trust Fund's Strategic Priority for Adaptation (SPA) and the Adaptation Fund (AF). The first three are relatively small, based on voluntary pledges and contributions from donors. As of December 2009 (www.climatefundsupdate.org), the total resources pledged to the LDCF, the SCCF and the SPA totalled USD 348 million, while the actual funds are about USD 285.9 million (EUR 240 million). Available funding provided so far — less than USD 500 million including assumed USD 100 million (EUR 85 million) investments through mainstreaming adaptation in Official Development Assistance (ODA) — therefore fall short of the estimated adaptation needs (Harmeling and Bals, 2008).

The AF, established under the Kyoto Protocol, is financed by a 2 % levy on certified emission reductions (CERs) related to Clean Development Mechanism (CDM) projects, in which the EU is expected to have a large share. The AF was operationalised in 2007 in Bali and latest estimates (UNFCCC, 2008) suggest it will have about USD 80–300 million per year between 2008–2012, in total USD 400 million–1.5 billion by 2012, assuming annual sales of 300–450 million CERs and a market price of EUR 17.5 per CER. As of 30 November 2009, it contained USD 28.25 million (EUR 23 million) (AFB, 2009).

The UNFCCC Copenhagen Accord of December 2009 recognises the need for enhanced action on adaptation to reduce vulnerability and build resilience in the most vulnerable developing countries, especially LDCs, SIDS and Africa, and outlines the main elements of developed countries' commitments for new, predictable and additional funding for both adaptation and mitigation in developing countries making use of the Copenhagen Green Fund. This includes a Fast Start programme — USD 30 billion or EUR 25 billion — for 2010–2012 and long-term finance of USD 100 billion (EUR 85 billion) annually by 2020 that will come from a wide variety of sources, public and private, bilateral and multilateral (UNFCCC, 2010b). The United Nations High-level Advisory Group on Climate Change Financing is tasked with drafting, before UNFCCC's COP16 at the end of

2010, recommendations on the governance structure and practical proposals to boost the implementation of short- and long-term financing for mitigation and adaptation in developing countries.

The EU (European Council, 10–11 December 2009) confirmed its readiness to contribute fast-start funding of EUR 2.4 billion annually for the years 2010 to 2012. In addition it recognised the need for a significant increase in public and private financial flows to 2020 and reiterated its commitment to provide its fair share of international public support. The EU also confirmed its endorsement of the Commission's estimate that the total net incremental costs of mitigation and adaptation in developing countries could amount to around EUR 100 billion annually by 2020, and indicated that the overall level of the international public support required is estimated to lie in the range of EUR 22–50 billion per year by 2020.

European level

Watkiss and Hunt (2010) also reviewed the information on the costs and benefits of adaptation in Europe, covering European sectoral, regional and national studies. The review found that the coverage of adaptation cost estimates is limited, though the evidence base in now growing as a result of such on-going Europe-wide studies as the EU FP7 ClimateCost project. The existing information has a very uneven distribution (Table 3.3), the largest number of studies, and those with most advanced and wide range of methods used, being for the coastal zone. There are also a number of cross-sectoral studies emerging, which look at the indirect effects of coastal flooding on, for example, health and tourism. For other sectors the coverage is more limited.

These studies use a range of methods and metrics for different time periods and with different assumptions, and therefore it is challenging to compare estimates, undertake a systematic review and build up a coherent picture of the overall costs of adaptation. Nevertheless, the information provides some early context and highlights important issues.

Estimates, in global aggregated studies, of adaptation costs for Europe include the UNFCCC (2007) review with an indicative assessment of USD 3–19 billion/year by 2030 (EUR 2.5–16 billion/year) for the infrastructure and coastal zones, while estimates given in the Stern Review (2006) based on costs of 0.05 to 0.5 % GDP imply adaptation costs for infrastructure for Europe of EUR 4–60 billion/year. In addition to investment and financial flow assessments, economic IAMs also report a wide range of estimates: the PAGE model, using the Stern analysis findings, assumes adaptation costs for the EU15 of USD 25–60 billion per year (EUR 21–50 billion/year) with a mean estimate of USD 45 billion/year (EUR 37 billion/year); other IAM studies report much lower adaptation costs, such as the adaptation and mitigation strategies (ADAM) project (Aaheim et al., 2010) which reports adaptation costs in western Europe in 2020 estimated at 0.04 % of GDP (USD 5 billion or EUR 4.1 billion) rising to USD 35 billion

Table 3.3 Coverage of studies for European vulnerable sectors

Sector	Coverage	Cost estimates	Benefit estimates
Coastal zones	Very high — infrastructure/erosion for Europe, regions, several countries as well as cities/local examples.	√√√	√√√
Energy	Medium — cooling/heating demand (autonomous adaptation) for Europe, some countries. Less on planned adaptation and supply *.	√√	√√
Infrastructure	Medium — adaptation cost estimates in several countries for flooding, but lower coverage of other infrastructure risks.	√√	√
Agriculture	High — coverage of farm-level autonomous adaptation benefits, but much less on costs and on planned adaptation.	√	√√
Health	Low/medium — adaptation costs for heat alert systems and food-borne disease, but less coverage of other health risks.	√	
Water	Low/medium — limited number of national, river basin or sub-national studies on water supply.	√	
Transport	Low/medium — some national and individual sector case studies.	√	
Tourism	Low — studies of winter tourism (Alps) and some of autonomous adaptation from changing summer tourism flow *.	√	√
Forestry and fisheries	Low — limited number of quantitative studies.	√	
Biodiversity/ecosystem services	Low — limited number of quantitative studies.	√	
Business and industry	Very low — no quantitative studies found.		
Building adaptive capacity	Low — selected studies only and only qualitative descriptions of benefits.	√	

Note: * can be considered an impact or an adaptation. See Watkiss and Hunt (2010) for extra notes and caveats.
Key: √ Low coverage with a small number of selected case studies or sectoral studies.
√ √ Some coverage, with a selection of national or sectoral studies.
√ √ √ More comprehensive geographical coverage, with quantified cost or benefit estimates at aggregate levels.

in 2050 (EUR 29 billion or 0.13 % of GDP) under a 2 °C scenario; OECD (de Bruin et al., 2009) estimates total weighed adaptation cost for a 2.5 °C temperature rise at 0.64 % of total output for Europe and 0.14 % for eastern Europe.

The sectoral and national studies provide some comparative information on adaptation costs. The PESETA coastal study (Richards and Nicholls, 2009) and Hinkel et al. (2009, 2010) reports costs of EUR 0.25–1.7 billion/year in the period 2010–2040 and EUR 0.3–3.5 billion/year in the period 2070–2100 across a range of temperature increase and sea-level rise scenarios. These studies also report that the economic benefits of adaptation options in reducing costs of inaction far outweigh the costs. For health, there are estimates of the costs of adaptation for diarrhoeal disease in Europe, based on costs of health interventions (Ebi, 2008; Markandya and Chiabai, 2009) which report annual adaptation costs in the period up to 2030 for Europe at USD 12–260 million/year for a range of scenarios and assumptions (EUR 10–215 million/year). These estimates indicate potentially large adaptation costs in Europe — billions of Euro per year in the short-term, potentially tens of billions per year in the longer-term.

A number of national studies have undertaken more comprehensive adaptation cost assessments, though these also have only partial coverage and, in general, much less information is available for the EU-12 than for EU-15. The most detailed national information is currently available for the Netherlands, Sweden and the United Kingdom but a large number of other European national studies will be published over the next few years, many of which will assess the costs of adaptation.

The individual national studies also imply large adaptation costs, particularly for flood protection. For example, the United Kingdom Foresight study estimated the total adaptation investment needed to address flooding — coastal, river and intra-urban — over the next 80 years at between GBP 22 billion and GBP 75 billion for a portfolio of responses, depending on the scenario, implying average annual costs of up to EUR 1 billion per year. Similarly, a recently conducted assessment on flood protection and flood risk management in the Netherlands estimates that the implementation of a comprehensive set of adaptation measures will cost EUR 1.2–1.6 billion per year up to 2050 and EUR 0.9–1.5 billion per year during the period 2050–2100. The recent Swedish evaluation estimated potentially large investment costs for adaptation to climate change across a wider range of sectors, including transport, energy, water treatment, infrastructure, flood protection and agriculture, at up to a total of EUR 10 billion for the period 2010–2100.

When scaled up to the European level, these national studies imply potentially higher adaptation costs (even for individual risks such as flooding) than found in many of the more aggregated sectoral studies, and certainly higher than many of the IAM assessments. At the EU level, they suggest costs of tens of billions/year when scaled to all countries and all sectors.

There are a number of studies that focus on vulnerable regions of Europe, and reveal important regional differences. These include assessments of the costs of sea-level rise in western Europe, the costs of adaptation for tourism in the Alps, and forthcoming work for the Mediterranean — health, cooling demand and water availability — and the Baltic.

Similar to the estimation of adaptation costs at the global level, assessment at a European scale is also extremely challenging, involving high levels of aggregation, simplifying assumptions — the simple scaling of likely investment needs — and a range of different methodological approaches and reporting metrics. Some caveats should therefore be highlighted as many case studies, for example, focus on technical adaptation and do not include possible behavioural change, do not clearly separate the investment that would be needed in the absence of climate change from that arising from climate change alone, or exhibit partial coverage of sectors and within sectors. In addition, there is still a large evidence gap reflected by low sectoral coverage and very little information on adaptation costs in many potentially important sectors such as water supply, tourism, industry, biodiversity and ecosystems at the European level. Overall, despite the current lines of evidence, there therefore remains a need to validate the estimates against more detailed, national and even local-level analysis (Watkiss and Hunt, 2010).

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Key EU projects

EEA (2008; page 204) gives an overview of key climate change impacts, vulnerability and adaptation projects under Interreg, FP6 and GMES initiatives. More and up-to-date information about Interreg, FP7 and FP6 research projects is available at:

- http://ec.europa.eu/research/environment/pdf/cop-15.pdf#view=fit&pagemode=none
- http://ec.europa.eu/research/environment/pdf/fp7_catalogue.pdf
- http://ec.europa.eu/research/environment/index_en.cfm?pg=projects&area=climate.
- http://ec.europa.eu/regional_policy/interreg3/index_en.htm;
- http://cordis.europa.eu/fp7/dc/index.cfm;
- http://cordis.europa.eu/fp6/dc/index.cfm?fuseaction=UserSite.FP6HomePage.

Below is a non-exhaustive list of some of these key projects:

- ADAGIO (Adaptation of Agriculture in European Regions at Environmental Risk under Climate Change);
- ADAM (Adaptation and Mitigation Strategies – Supporting European Climate Policy);
- AdaptAlp (Adaptation to Climate Change in the Alpine Space);
- AlpWaterScarce (Water Management Strategies against Water Scarcity in the Alps);
- AMICA (Adaptation and Mitigation — an Integrated Climate Policy Approach);
- ASCCUE (Adaptation Strategies for Climate Change in the Urban Environment);
- ASTRA (Developing Policies & Adaptation Strategies to Climate Change in the Baltic Sea Region);
- BaltCICA (Climate Change: Impacts, Costs and Adaptation in the Baltic Sea Region);
- BalticClimate (Baltic Challenges and Chances for local and regional development generated by Climate Change);
- BRANCH (Biodiversity Requires Adaption in Northwest Europe under a CHanging climate);
- CapHaz-Net (Social capacity building for natural hazards: Toward more resilient societies);
- CAVIAR (Community Adaptation and Vulnerability in the Arctic Regions);
- CCTAME (Climate Change — Terrestrial Adaption and Mitigation in Europe);
- CIRCE (Climate change and impact research: the Mediterranean environment);
- CIRCLE 2 (Climate Impact Research for a Larger Europe);
- ClimateCost (Full Costs of Climate Change);
- Clim-ATIC (Climate change — Adapting To the Impacts by Communities in the northern periphery);
- ClimAlpTour (Effects of climate change on Alpine tourism);
- ClimChAlp (Climate Change, Impacts and Adaptation Strategies in the Alpine Space);
- CLIMSAVE (Climate change integrated assessment methodology for cross-sectoral adaptation and vulnerability in Europe);
- CLISP (Climate Change Adaptation by Spatial Planning In The Alpine Space);
- CoastAdapt (The Sea as Our Neighbour: Sustainable Adaptation to Climate Change in Coastal Communities and Habitats on Europe's Northern Periphery);
- DAMOCLES (Developing Arctic Modeling and Observing Capabilities for Long-term Environmental Studies);
- ESPACE (European Spatial Planning — Adapting to Climate Events);
- GRaBS (Green and Blue Space Adaptation for Urban Areas and Eco Towns);
- MEDIATION (Methodology for Effective Decision-making on Impacts and Adaptation);
- NORADAPT (Community Adaptation and Vulnerability in Norway);
- PESETA (Projection of Economic impacts of climate change in Sectors of the European Union based on boTtom-up Analysis);
- RESPONSES (European responses to climate change: deep emissions reductions and mainstreaming of mitigation and adaptation);
- Safecoast (Sharing knowledge on climate change & coastal flood and erosion management);
- VACCA (Vulnerability and Adaptation to Climate Change in the Arctic).

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