6 Adaptation to climate change

Key messages

- Adaptation aims at increasing the resilience of natural and human systems to current and future impacts of climate change. Adaptation occurs mainly at sub-national and local levels but involves all levels of decision-making from municipalities to international organisations.
- Adaptation is a cross-sectoral and transboundary issue which requires comprehensive integrated approaches. Integration of adaptation into sectoral policies at European and national levels is key to a long-term reduction in the vulnerability of ecosystems, economic sectors, landscapes and communities to climate change impacts. Integrating climate change into all main policy actions and measures would benefit from an enhanced sharing of information on current and planned adaptation activities in Europe.
- Good adaptation practices should be appropriate, proportionate and cost-effective in the long term, and links between adaptation and mitigation need to be considered when they are being developed. Substantial work is needed to better assess adaptation costs in order to support further integrated policy-making.

6.1 Europe needs to adapt

The previous chapters presented an overview of European impacts, showing that many regions are vulnerable to climate change and that impacts have already been observed in many vulnerable systems. Most of the impacts are adverse and are generally projected to worsen, certainly beyond a few decades. There is therefore a need for all countries, developing and developed, to adapt to climate change ([5]). Adaptation offers opportunities to make Europe more resilient to climate change.

The EU has agreed to limit the increase in the long term of global mean temperature to 2 °C above pre-industrial levels. Even if this goal is achieved through stringent world-wide mitigation actions to stabilise global GHG concentrations, some impacts will remain, at least in the short- and medium-term, making adaptation imperative to reduce vulnerability and enhance resilience. Europe has to adapt to climate change and also has a moral obligation to assist developing countries as they are most vulnerable in terms of communities, economic sectors and ecosystems. This should be done in the context of the Nairobi Five-year programme of work on impacts, vulnerability and adaptation to climate change (UNFCCC, 2006), the National Adaptation Plans of Actions (NAPAs) and the Bali Action Plan (UNFCCC, 2007c). A number of developing countries have prepared NAPAs using the UNDP Adaptation Policy Framework (UNDP, 2004). Furthermore, the Bali Action plan, resulting from the most recent COP/MOP meetings (Conference and Meeting of the Parties, December 2007), recognises that adaptation will need to be explicitly included in a global post-2012 climate change agreement, currently being negotiated with the aim of reaching an agreement in Copenhagen by the end of 2009 (UNFCCC COP15).

Climate change does not pose a threat at all levels of change and for all sectors or regions. In some areas in the world, agriculture, for example,

([5]) Adaptation to climate change is defined by the IPCC as 'Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities. Various types of adaptation can be distinguished, including anticipatory, autonomous and planned adaptation' (IPCC, 2007). Climate change is one driver of global change, to which adaptation is needed. Adaptation includes pro-active and reactive measures, which relate mainly to planned adaptation, as well as autonomous actions. Mitigation aims at avoiding the unmanageable impacts, while adaptation aims at managing the unavoidable impacts.

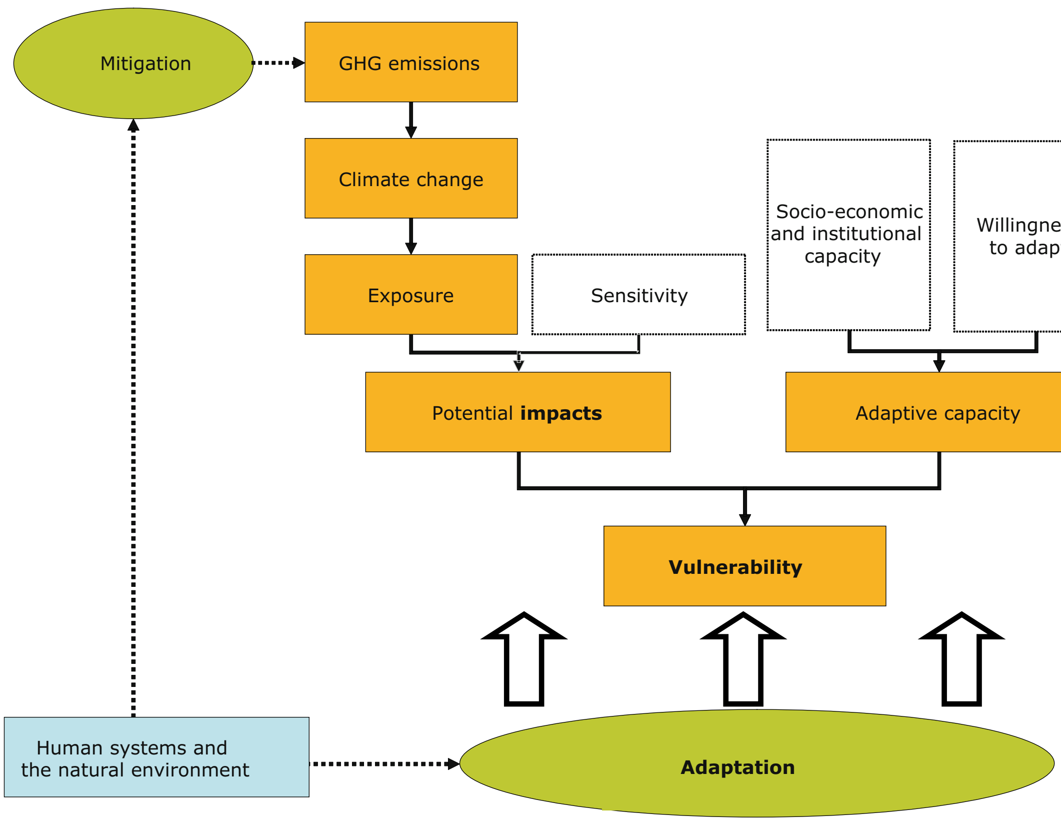
can benefit from small temperature increases and related CO_2 fertilisation, at least in places without reduced precipitation. Climate change may also provide opportunities for innovation in technology and governance in other sectors (e.g. tourism, energy supply, water management, health, construction and shipping). Reducing vulnerability and capturing opportunities both require pro-active adaptation actions, for which integrated analysis and tools such as spatial planning are essential (Uhel and Isoard, 2008). There is now significantly improved understanding of the relationship between impacts, which forms the basis for the 'reasons for concern', and of vulnerability, including an ability and willingness to adapt to impacts (see Figure 6.1 and Grothmann and Patt, 2005).

Recognising the necessity for Europe to adapt to climate change impacts, the European Commission in June 2007 adopted a Green Paper 'Adapting to climate change in Europe — options for EU action' which sketches four pillars of actions (EC, 2007). These are:

- 'Early action in the EU' (integrate adaptation when implementing existing and future legislation and policies, integrate adaptation into existing Community funding programmes, develop new policy responses);
- 'Integrating adaptation into EU external actions';
- 'Reducing uncertainty by expanding the knowledge base through integrated climate research';
- 'Involving European society, business and the public sector in the preparation of coordinated and comprehensive adaptation strategies'.

The publication of the Green Paper included an extensive regional stakeholders consultation process. The European Commission is planning to adopt, in late 2008, a White Paper framing a European adaptation strategy and options for adaptation, accompanied by an Impact Assessment of policy proposals.

Figure 6.1 Conceptual model for climate change impacts, vulnerability and adaptation



Source: Isoard, Grothmann and Zebisch, 2008.

Many adaptation options are already available, which are usually location- and sector-specific. Nowadays, adaptation is seldom undertaken for the sake of climate change alone, and is generally integrated into other cross-cutting and precautionary policy actions, such as disaster preparedness, coastal zone management, rural development, health services, spatial planning and regional development, ecosystems and water management. An increasing consideration of adaptation issues in decision-making is expected to lead to the development of new assessment tools and more integrated adaptation measures.

However, there are limits to adaptation. Natural systems often have a lower adaptive capacity than human systems, especially when certain thresholds — which are poorly but increasingly understood — are exceeded. More diverse systems are likely to adapt to climate change better. But even for human systems (i.e. all economic sectors) there will be limits, influenced by social, technological, economic, environmental, political and institutional constraints. With increasing impacts of climate change, adaptation costs will increase and response options may decrease. The costs of adaptation are estimated to be significant (although only orders of magnitude are known so far), but we can assume that the longer we wait before taking action the higher the costs will be. The range of estimated global costs for adaptation is 30–90 billion USD/year ([6]), and this is calculated as additional to Official Development Assistance (ODA) ([7]), which averaged 80 billion USD/year over recent years (EEA (2007), UNFCCC (2007a, 2007b), UNDP (2007), Oxfam (2007), World Bank (2007) and OECD (2008)).

6.2 Adaptation occurs at transboundary, sub-national and local levels

Adaptation is a crosscutting issue since it aims at enhancing resilience to climate change impacts which affect virtually all economic sectors in Europe, such as water management; agriculture; forestry; health; energy; transport; tourism; nature and soil protection, biodiversity and ecosystems goods and services; fisheries. Integrating climate change adaptation into sectoral policies is therefore one of the key approaches in Europe together with mainstreaming into EU funding mechanisms. Integration of climate change into other policy areas aims at protecting citizens and nature, and making economic activities less vulnerable by appropriate and proportionate adaptation measures. Examples of such measures include: health/heat action plans, vaccination, health system planning, flood risk planning (early warning systems), drought and water scarcity risk management, water demand management, coastal and flood defences, economic diversification, natural hazard monitoring, reinforcing the built environment (e.g. roads, bridges, electric wires), land-use management, and greening of cities.

Economic sectors that are particularly concerned with adaptation include energy supply, health, water management, agriculture, tourism and transport. Adaptation is very much about managing the risks associated with future climate change impacts. In many cases a link with disaster management will also be appropriate. Adaptation occurs primarily at transboundary (e.g. river catchments), sub-national and local levels, and therefore involves many levels of decision-making. The choice of the level of intervention will be different for different regions, landscape types and sectors. The transboundary nature of climate change and associated adaptation responses, together with the subsidiarity principle, are important factors to consider when implementing strategies.

In addition, linkages between adaptation and mitigation also have to be considered (Swart and Raes, 2007), particularly when one looks forward towards mainstreaming and coordinating future actions. Some adaptation options can be developed in synergy with mitigation, for example in the land and water management sectors. The development of mitigation measures also needs to consider vulnerabilities and adaptation options. Identifying possible conflicts between mitigation and adaptation is key for avoiding mal-adaptation such as, in some cases, artificial snow making, transfer of water, air conditioning or desalination. However, there is a need to develop criteria for clearly defining and avoiding mal-adaptation, since

([6]) UNDP (2007) reports estimates of costs needed for investing in adaptation of about USD 86 billion annually by 2015. UNFCCC (2007a, 2007b) estimated that the overall additional investment and financial flows needed for adaptation in 2030 amount to several tens of billion US dollars (e.g. USD 14 billion for agriculture, forestry and fisheries, USD 11 billion for water supply, USD 5 billion for diarrhoeal disease, malnutrition and malaria, USD 11 billion for beach nourishment and dykes, and USD 8–130 billion for adapting new infrastructure). The World Bank (2007) reported an estimate of USD 30 billion for adaptation costs.

([7]) The long-standing development assistance target is 0.7 % of the Gross National Income for rich countries. The EU and G8 commitment of 2005 included a pledge to double aid flows by 2010, representing a USD 50 billion increase.

it can lead to additional greenhouse gas emissions which can offset mitigation efforts.

Consequently, adaptation options have to be tailor-made to the specifics of the geographic area considered in terms of vulnerable landscape types (e.g. coastal areas, wetlands and rivers, mountains and glaciers, the Mediterranean, the semi-Arctic) and sectors involved, with a view to implementing measures at the appropriate level of decision-making (EU, national, regional, local). Different vulnerable systems at different geographic levels will require different approaches.

6.3 From European and national strategies to regional and local implementation

EU Member States are at different stages of preparing, developing and implementing national adaptation strategies, depending on the magnitude and nature of the observed impacts, assessment of current and future vulnerability, and capacity to adapt (see details in Table 6.1). All countries have also submitted information on their adaptation plans in their 4th National Communication to the UNFCCC in 2005. In addition, some actions and measures are increasingly also being taken at regional and local levels.

National strategies provide the framework for adaptation actions, many of which have to be implemented at sub-national and local levels (regions, provinces or municipalities). Various regionally-oriented initiatives are underway in Europe, particularly under the European Commission INTERREG programme that links research and policy development ([8]). National and European action can provide and strengthen the enabling circumstances for regional and local adaptation by focusing on specific regions that are particularly vulnerable to climate change (e.g. the Alps). National and European information sources, such as this report, contribute to enhancing the knowledge base for identifying vulnerable areas and setting the context for implementing regional and local adaptation action. Specific impact indicators can be directly linked to the economic sectors that have to prioritise, develop and implement adaptation strategies.

European countries emphasise different types of adaptation measure. It is important to consider an analytical framework that could help to assess these activities within countries and provide an overview of actions. Massey (2007) has developed a draft framework for this purpose ([9]), which categorises adaptation measures from three main angles, (1) the level or stage of adaptation measures (i.e. whether a programme is in place or whether a country is contemplating a specific action), (2) the objective of the actions (i.e. why adaptation is taking place, e.g. building adaptation capacity, reducing risk and sensitivity) and (3) the issue or problem that adaptation aims to address (e.g. coastal zone management, health and disease management). The PEER network ([10]) has also recently started a research project on a comparative analysis of national adaptation strategies and sectoral policies for adaptation in various European countries, including a few national and regional case-studies.

However, there is a lack of information across Europe on impacts and vulnerability assessment at regional and local levels, and on adaptation activities and measures planned or currently being implemented by countries. There is therefore a need to enhance information-sharing on impacts, vulnerability and adaptation to climate change, which requires overall coordination. This is re-inforced by the need to inform the many levels of decision-making involved in practical adaptation responses. Ensuring a wider access to and understanding of impacts and vulnerability, for example with climate and socio-economic scenarios and databases on good practice adaptation policies in the various vulnerable sectors (with a focus on regional specificities), would certainly help expanding the knowledge base across Europe.

The relevance of adaptation at the EU level is primarily concerned with coordinating information sharing, and encouraging an appropriate, proportionate and integrated implementation of adaptation measures at national, regional and local levels. The integration of adaptation into EU sectoral policies, and in addition into structural/cohesion

([8]) INTERREG and other relevant projects include: ASTRA (Developing Policies & Adaptation Strategies to Climate Change in the Baltic Sea Region), AMICA (Adaptation and Mitigation — an Integrated Climate Policy Approach), ADAGIO (Adaptation of Agriculture in European Regions at Environmental Risk under Climate Change), BRANCH (Biodiversity Requires Adaption in Northwest Europe under a CHanging climate), CIRCLE (Climate Impact Research for a Larger Europe), ClimChAlp (Climate Change, Impacts and Adaptation Strategies in the Alpine Space) and ESPACE (European Spatial Planning — Adapting to Climate Events).

([9]) See also Füssel and Klein (2004).

([10]) Partnership for European Environmental Research (PEER), http://peer-initiative.org.

funds and external relations, are key instruments in this respect, together with fostering research and involving stakeholders.

Only an integrated approach to addressing the cross-cutting nature of adaptation will deliver long-lasting measures that will enhance resilience in Europe. The issues to be considered are not only sectoral, but very importantly also cover regional and local specifics in terms, for example, of landscape types, land use and biodiversity.

Table 6.1 EU Member States progress towards National Adaptation Strategies (NAS)

Countries	Impacts, vulnerability and adaptation assessments	NAS under preparation	NAS adopted	Web links
Austria	Anpassungsstudie			www.klimaanpassung.lebensministerium.at/
Belgium	SSD	X (2012)		
Bulgaria	X			www2.moew.government.bg/recent_doc/international/climate/NAPCC_Final_English.doc
Czech Republic		X (end 2008)		www.env.cz/AIS/web-en.nsf/pages/Climate_Change
Cyprus				
Denmark	Ministry of Climate and Energy		2008	www.kemin.dk/NR/rdonlyres/1247B5C0-0BAD-464A-9997-2EAB952D9494/56490/klimatilpasningsstrategi.pdf www.klimatilpasning.dk
Estonia	ASTRA	X (2009)		www.astra-project.org
Finland	FINADAPT		2004	www.mmm.fi/attachments/5eWDKveQh/5h0aZ7Iid/Files/CurrentFile/Finlands_national_adaptation_srtrategy_julkaisu.pdf www.ymparisto.fi/default.asp?contentid=227544&lan=EN
France	GICC		2006	www.ecologie.gouv.fr/Adaptation-au-changement.html
Germany	KomPass; Klimazwei; KLIMZUG	X (1st draft end of 2008)		www.anpassung.net www.klimazwei.de
Greece	Ministry of Environment & Athens Academy			
Hungary	VAHAVA		2008	http://klima.kvvm.hu/documents/14/nes_080219.pdf
Iceland	VO			http://eng.umhverfisraduneyti.is/media/PDF_skrar/Stefnumorkun_i_loftslagsmalum_enlokagerd.pdf
Ireland	ERTDI; CCRP			www.environ.ie/en/PublicationsDocuments/FileDownLoad,1861,en.pdf www.epa.ie
Italy	X			www.conferenzacambiamenticlimatici2007.it www.apat.gov.it/site/en-GB
Latvia	ASTRA	X (2009)		www.vidm.gov.lv/eng www.astra-project.org
Liechtenstein	X			www.energie.zh.ch/internet/bd/awel/energie/de/themen/energieplanung.html
Lithuania	ASTRA			www.astra-project.org
Luxembourg				
Malta				www.mepa.org.mt/environment/index.htm?climate_change/mainpage.htm&1
Netherlands	National Programme for Spatial Adaptation to Climate Change (ARK), CcSP, Knowledge for Climate		2008	www.vrom.nl/pagina.html?id=2706&sp=2&dn=7222 www.vrom.nl/pagina.html?id=2706&sp=2&dn=7502 www.climatechangesspatialplanning.nl http://international.vrom.nl/pagina.html?id=10918
Norway	NORADAPT, NORKLIMA	X (end 2008)		www.regjeringen.no/en/dep/md/Whats-new/News/2008/ber-om-innspill-til-redegjorelse-om-klim.html?id=51146 www.cicero.uio.no/projects/detail.aspx?id=30182&lang=EN www.forskningsradet.no/servlet/Satellite?pagename=norklima/Page/HovedSide&c=Page&cid=1088796719022
Poland	X			

Table 6.1 EU Member States progress towards National Adaptation Strategies (NAS) (cont.)

Countries	Impacts, vulnerability and adaptation assessments	NAS under preparation	NAS adopted	Web links
Portugal	SIAM			www.siam.fc.ul.pt/siam.html
Romania	X	X (end 2008)		www.mmediu.ro
Slovakia	X			
Slovenia	X			
Spain	ECCE + Impacts on coastlines		2006	www.mma.es/portal/secciones/cambio_climatico/areas_tematicas/impactos_cc/eval_impactos.htm www.mma.es/portal/secciones/cambio_climatico/areas_tematicas/impactos_cc/imp_cost_esp_efec_cc.htm www.mma.es/portal/secciones/cambio_climatico/areas_tematicas/impactos_cc/pnacc.htm
Sweden	SWECLIM; SWECIA; CLIMATOOLS			http://mistras.internetborder.se/mistra/english/researchresults/researchprogrammes/completedprogrammes/sweclimswedishregionalclimatemodellingprogramme.4.1eeb37210182cfc0d680007760.html www.mistra.org/mistra/english/researchresults/researchprogrammes/activeprogrammes/mistrasweciaclimateimpactsandadaptation.4.a791285116833497ab800017356.html www.foi.se/FOI/Templates/ProjectPage____5846.aspx www.sweden.gov.se/sb/d/574/a/96002 www.regeringen.se/sb/d/8756/a/91682
Switzerland	OcCC			www.bafu.admin.ch/klima/00469/00810/index.html?lang=fr www.occc.ch/index_e.html
Turkey				
United Kingdom	UK National Risk Assessment + UKCIP studies		2008	www.ukcip.org.uk www.defra.gov.uk/adaptation www.defra.gov.uk/Environment/climatechange/uk/legislation/index.htm

7 Economic consequences of climate change

7.1 Introduction

A wide range of economic effects will result from climate change in Europe. These include effects on services associated with the natural environment (including forests and fisheries), coastal zones, agriculture, tourism, energy, human health and the built environment.

The observed and projected effects of climate change in Europe differ across regions and sectors. Many of the impacts are projected to be adverse and to lead to economic costs or losses, though there will also be economic benefits (gains). There is a strong distributional pattern for the economic effects predicted across Europe, with a significant trend towards more potentially adverse impacts in south-eastern Europe and the Mediterranean (e.g. in relation to energy demand, agricultural productivity, water availability, health effects, summer tourism, ecosystems). In northern and western Europe a more complex balance between negative and positive impacts is projected for moderate levels of climate change in the coming decades, with potential benefits derived from new farming and tourism opportunities. As climate change continues, eventually the negative impacts are projected to dominate.

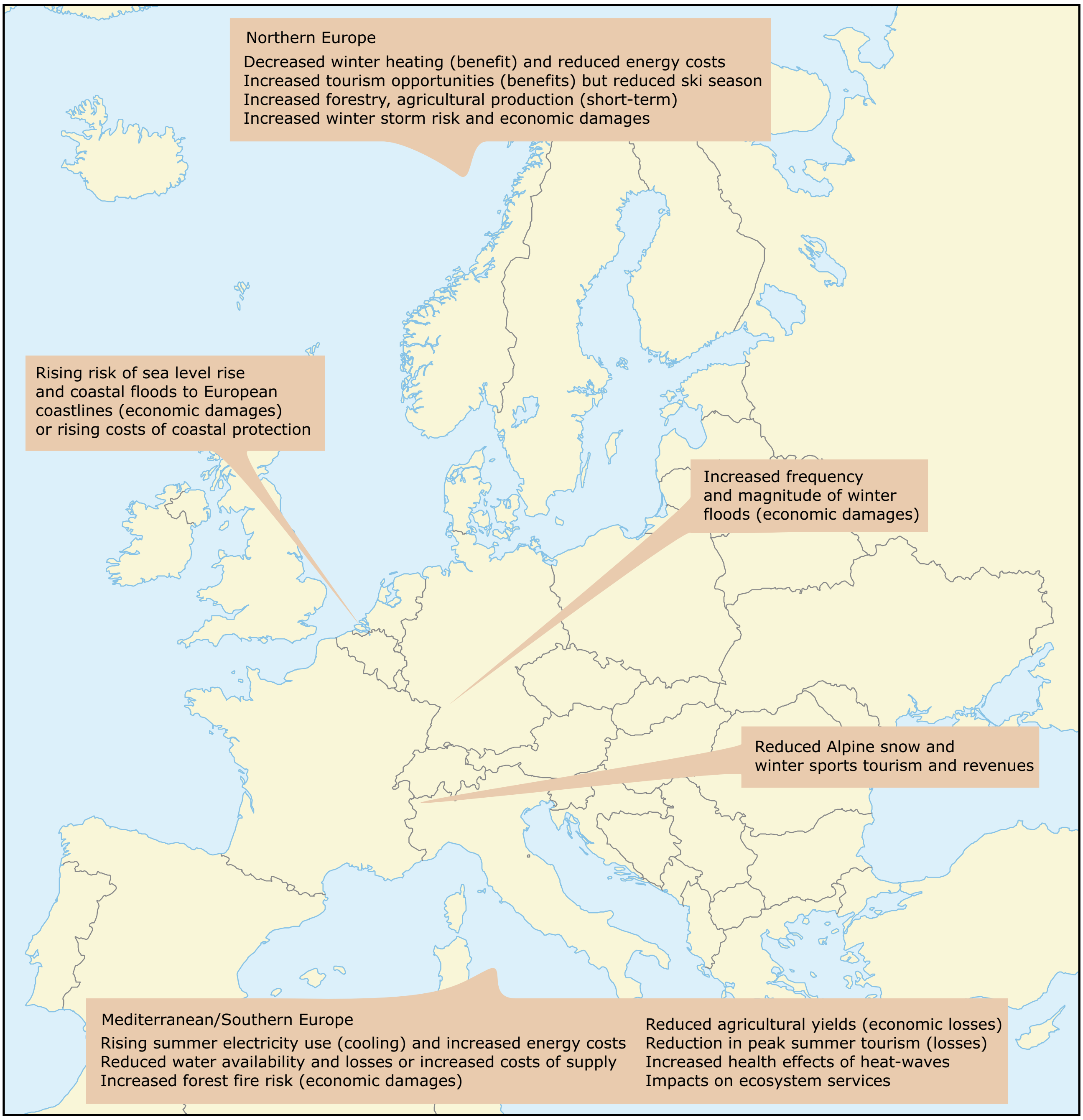
It is also evident that even if emissions of greenhouse gases were to stop today, changes in climate will continue for many decades. Therefore, in addition to mitigation, it is essential to develop proportionate adaptive responses (adaptation) as a means of moderating damages or realising opportunities associated with climate change. There is therefore also a need to consider the economic aspects of adaptation. However there has so far been more research on the physical impacts of climate change than on the costs of these impacts (their economic valuation) and of adaptation actions.

The economic costs of climate change impacts if no adaptation were to take place are known as the 'costs of inaction'. They relate to both direct and indirect impacts, including the associated socio-economic developments. Estimates of these costs and the costs of adaptation are increasingly helping to inform the policy debate, in particular in discussing the level of mitigation effort that is needed globally.

As a first indicator, direct losses from weather-related natural disasters are analysed. Past trends indicate that economic losses due to such disasters have increased considerably, particularly in recent years. Since no statistically significant increase in the frequency of events like floods has yet been observed, the increase in economic losses is probably determined mainly by other factors, such as a possible increase in the intensity of flood events, the overall increase in wealth and possibilities for insurance, and the increased amount and distribution of infrastructure vulnerable to such disasters. We have therefore also included a separate indicator on economic losses from floods (which comprise the largest share of weather-related natural disasters in Europe) for which such socio-economic effects have been removed or 'normalised' in order to assess the actual weather/climate-related trend better. It is shown that by using such a normalisation method the losses are simulated to be generally lower. Additional information and analysis are presented in subsequent sections for coastal areas, public water supply, agriculture and forestry, biodiversity loss and ecosystem goods and services, energy, tourism and recreation, health and the society as a whole. These sections should be read in connection to the indicator information presented in Chapter 5 which is not repeated here.

A brief overview of the economic effects of projected climate change across Europe is presented in the map below.

Map 7.1 Examples of potential economic effects across Europe



Source: Based on Watkiss, 2006.

7.2 Direct losses from weather disasters ([11])

Key messages

- About 90 % of all natural disasters in Europe that have occurred since 1980 are directly or indirectly attributable to weather and climate. About 95 % of economic losses caused by catastrophic events ([12]) have resulted from these weather and climate-related disasters.
- The average number of annual disastrous weather and climate-related events in Europe increased by about 65 % over 1998–2007 compared with the annual average for the 1980s, while non-weather events (e.g. earthquakes) remained stable. An unknown share of this increase can be attributed to climate change, the rest to changes in the sensitivity of human/societal systems.
- Overall losses resulting from weather- and climate-related events have increased clearly during the past 25 years. Even though social change and economic development are the main factors responsible for this increase, there is evidence that changing patterns of weather disasters are also drivers. However, it is still not possible to determine the proportion of the increase in damages that might be attributed to anthropogenic climate change.
- While in the immediate future disaster losses are projected to increase mainly as a result of societal change and economic development, the most severe effects of anthropogenic climate change on economic assets are expected in the second half of the century.

Relevance

Changes in the frequency and intensity of storms, floods and extreme temperatures affect the financial sector, including the insurance sector, through the amount of compensation payments. Examining insurance claims related to weather disasters can help to identify the sectors (e.g. agriculture, forestry, infrastructure, industry or private households) that are most affected by damage and/or could be most affected in future.

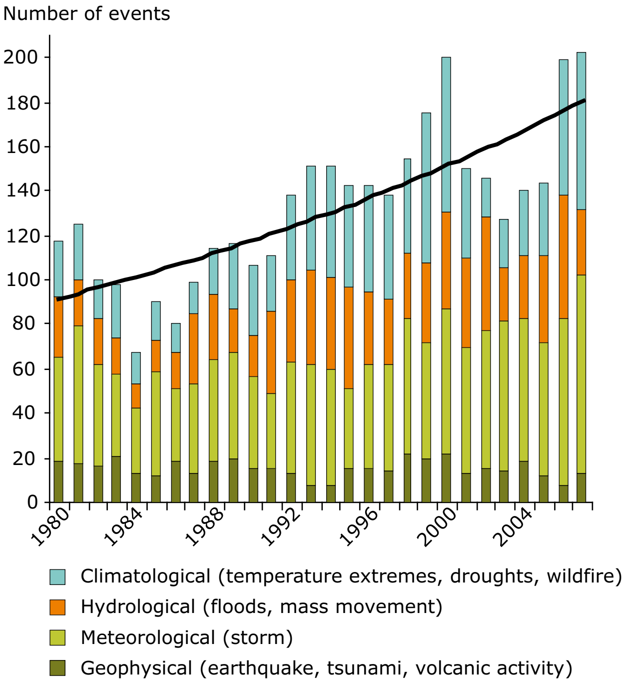
A recently published report from the United Nation Environment Programme's Finance Initiative (UNEP FI, 2006) estimated that losses from weather events are doubling globally every 12 years. Even though the observed increase in losses is dominated by socio-economic factors (such as population growth, increased number of habitations in vulnerable areas, increased wealth, increased amount and value of vulnerable infrastructure), there is evidence that changing patterns of natural disasters are also drivers (Figure 7.1). It is however not known how much of this increase in losses can be attributed to anthropogenic climate change (Höppe *et al.*, 2006).

Insurance mechanisms are key in risk management and hence can play an important role in adapting to climate change by covering the residual risks and providing incentives for risk reduction. Through their underwriting policy, the (re)insurance companies can indeed increase risk awareness and provide incentives for risk reduction. Insurance companies have inherent interests in minimising the impacts of climate change in order to maintain residual risks insurable. Through their investment policy and asset management, the financial sector as a whole (savings, loans and insurance companies as well as other institutional investors) has great influence on companies' investment decisions. They can therefore ensure that any investments made are more climate-resilient and channel money into projects related to adaptation and mitigation of climate change. On the other hand the industries with greatest exposures will have to respond increasingly with innovative products, e.g. catastrophe bonds (Bouwer *et al.*, 2007).

([11]) The most recent Munich Re dataset, which is not normalised, has been used for presenting past trends in losses due to all weather-related natural disasters (i.e. this section). This is different from the normalized indicator on losses from river flood disasters presented in Section 7.3.

([12]) The following definitions apply (Munich Re): (1) A 'major catastrophe' is defined as a 100+ fatalities event with overall losses in excess of USD 200 m; (2) A 'devastating catastrophe' is defined as a 500+ fatalities event with overall losses in excess of USD 500 m; (3) A 'great natural catastrophe' or 'GREAT disaster' is defined as leading to thousands of fatalities with the economy being severely affected and extreme insured losses (UN definition); interregional or international assistance is necessary, hundreds of thousands are made homeless.

Figure 7.1 Natural disasters in Europe 1980–2007



Source: Münchener Rückversicherungs-Gesellschaft (Munich Re), Geo Risks Research, NatCatSERVICE, 2008.

Past trends

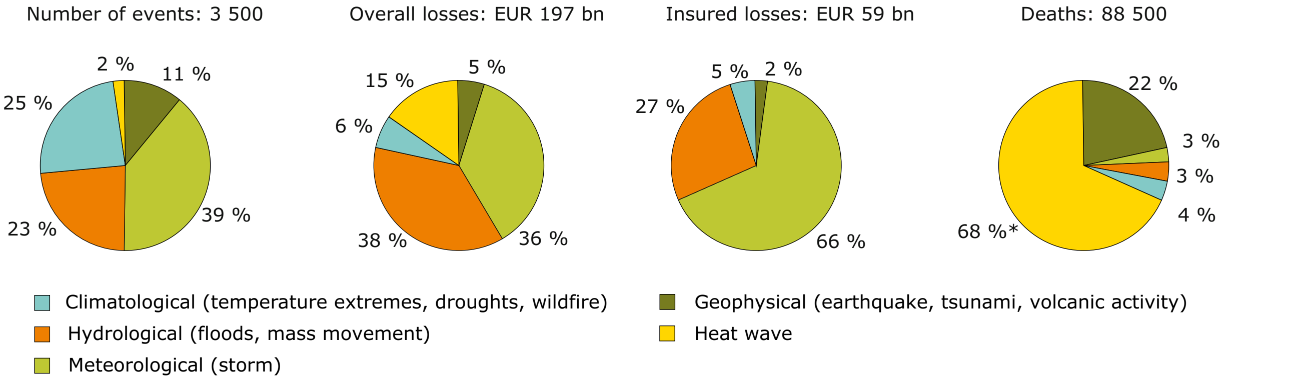
In Europe, 64 % of all loss events since 1980 are directly attributable to weather and climate events (storms, floods and heat-waves) and 25 % to wild fires, cold spells, landslides and avalanches, which are also linked to weather and climate. 95 % of the overall losses and 78 % of all deaths caused by disastrous events result from such weather and climate-related events (Figure 7.2).

The annual average number of these weather- and climate-related events in Europe increased during the period 1998–2007 by about 65 % compared with the 1980s, while non-climatic events, such as earthquakes, remained stable (Figure 7.1). An unknown share of this increase can be attributed to climate change, the rest to changes in the sensitivity of human/societal systems.

In Europe, overall losses caused by weather- and climate-related events increased during the period 1980–2007 from a decadal average of less than EUR 7.2 billion (1980–1989) to about EUR 13.7 billion (1998–2007). Six of the nine years with the largest overall losses in this period have occurred since 1999 (Figure 7.3). The insured portion of the losses generally rose, although with great year-to-year variability.

Particularly disastrous extreme events in Europe in recent years include the severe flooding in central Europe in August 2002 and the extended heat wave in 2003. The 2002 flooding in Austria, the Czech Republic, Germany, Slovakia and Hungary resulted in overall losses of about EUR 16.8 billion and insured losses of about EUR 3.4 billion (Munich Re, 2008). The 2003 heat wave (Schär *et al.*, 2004) resulted in many more deaths in north-western Europe and the Mediterranean over and above the normal numbers (Kovats and Jendritzky, 2006; Robine *at al.*, 2007) and caused significant losses in the agricultural and energy-producing sectors. As an example, the total loss from the 2003 hot summer in France (including the stress on power generation, the transport system, forests and other ecosystems, including fires, reduced wine production and decreased agricultural productivity) has been estimated at 0.1/0.2 % of

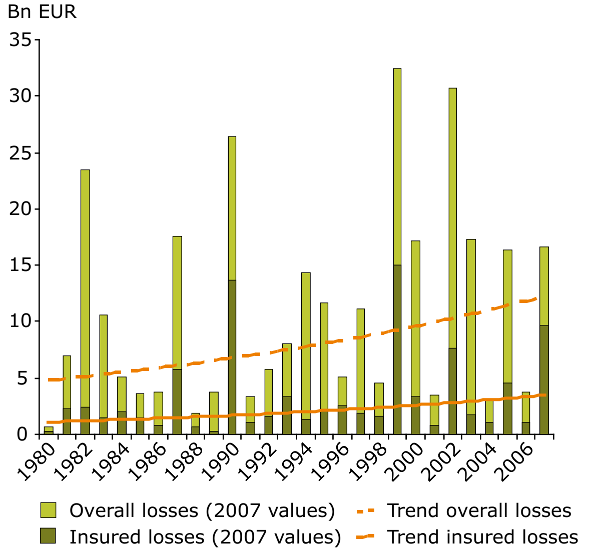
Figure 7.2 Natural disasters in Europe 1980–2007



Note: * Most of the casualties were elderly people who died in the 2003 summer heat wave (surmortality).

Source: Münchener Rückversicherungs-Gesellschaft (Munich Re), Geo Risks Research, NatCatSERVICE, 2008.

Figure 7.3 Overall and insured losses from weather disasters in Europe 1980–2007



Source: Münchener Rückversicherungs-Gesellschaft (Munich Re), Geo Risks Research, NatCatSERVICE, 2008.

GDP, equivalent to EUR 15–30 billion. The 2003 summer was also estimated to have increased building subsidence claims in the United Kingdom by 20 %, with estimated impacts of GBP 30 to GBP 120 million and damage to transport infrastructure (rail buckling and road subsidence) of £40 million (Watkiss *et al.*, 2006).

Projections

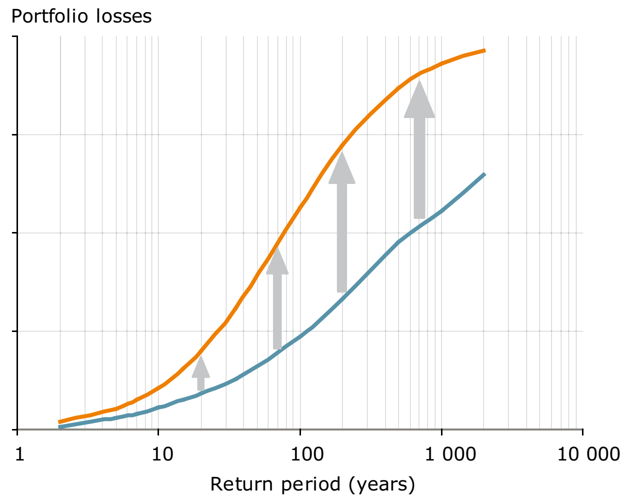
Extreme weather events such as heat waves, droughts and heavy precipitation are projected to increase in frequency and intensity in Europe, and the number of people at risk is also projected to grow (IPCC, 2007a). However, the associated time scale and hazard over the next 20 years remains uncertain. The most severe effects of anthropogenic climate change are expected in the second half of the century.

Predicting the future effects of extreme events also remains difficult because of increasing exposure caused by changes in economic development, which increases the value and density of human and physical capital. Disaster losses are expected to rise more rapidly than average economic growth, stressing the importance of risk reduction (Bouwer *et al.*, 2007).

Nonetheless, Swiss Re has estimated that in Europe the costs of a 100-year ([13]) storm event could double by the 2080s with climate change (to EUR 40 billion compared with EUR 20 billion today), while average storm losses are estimated to increase by 16–68 % over the same period. The Association of British Insurers (ABI, 2005, 2007) reports an estimated increase in worldwide annual losses from hurricanes, typhoons and windstorms by two-thirds by the 2080s, to EUR 18 billion; in addition, they indicate that subsidence costs in the United Kingdom could increase by 50 % on average clay-soil areas over the next 50 years due to climate change, and that by the 2040s, more than half of all European summers are projected to be warmer than that of 2003 which resulted in huge increases in hospital admissions and premature deaths. Finally, they report that by 2050 around a quarter of working hours will be hotter than 'comfort levels' in London.

The possible future increases in damage will enhance the vulnerability of the insurance sector (see Figure 7.4) and have important implications for the role of financial services under climate change (IPCC, 2007b). In high-risk areas people will experience increasing difficulty or costs in getting adequate insurance. This is likely

Figure 7.4 Example of the adjustment of loss distribution as a consequence of changing risk



Note: Models can produce a probable maximum loss (PML) curve, a chart that is a function of the highest amount an insurer is set to lose at a range of return periods (years).

Source: Munich Re, 2007.

([13]) In average happening once in 100 years only.

Photo: © Münchener Rück Stiftung, München

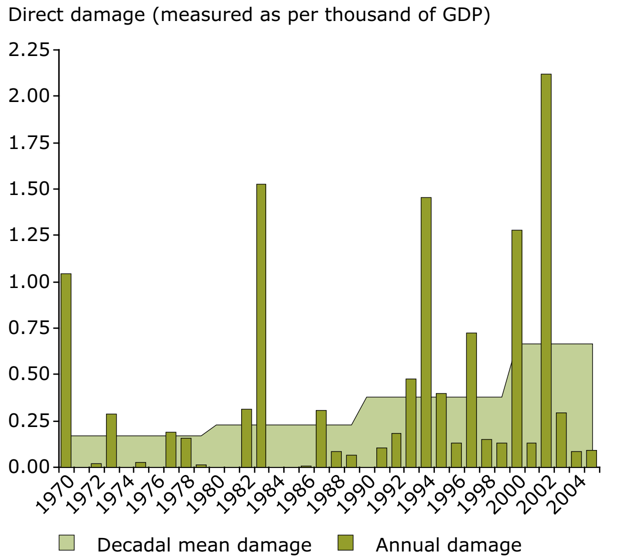
to lead to greater levels of uninsured assets, particularly to socially-deprived groups, hence exacerbating inequalities. Thus governments may need to consider new ways of ensuring that especially poorer and more vulnerable people will still be able to have insurance and/or may be compensated for possibly increasing losses in future (e.g. through public-private insurance schemes such as those introduced in Belgium and proposed in the Netherlands (Bouwer *et al.*, 2007)). Nevertheless, the noticeable differences in the climate predictions across Europe show that there is no one-size-fits-all solution and suggest, more specifically, that European countries might need to implement different insurance schemes to secure sustainable and flexible loss-compensation systems.

7.3 Normalised losses from river flood disasters

Key messages

- Economic losses as a consequence of extreme flood events in recent years have been dramatic. Flood disasters ([14]) increased significantly in Europe during the 1990s and the 2000s. The estimated losses in central Europe in 2002 were EUR 17.4 billion. This is more than the GDP of Bulgaria in that year. The cost of floods in the United Kingdom in summer 2007 is estimated at around EUR 4.3 billion.
- Although there is scientific evidence for a continuing intensification of the water cycle there is no homogeneous trend in extreme river flows/discharge in Europe.
- Analyses of long-term records of flood losses indicate that societal, environmental and economic factors clearly play an important role in the observed upward trends.

Figure 7.5 Flood losses per thousand of GDP in the EU 1970–2005



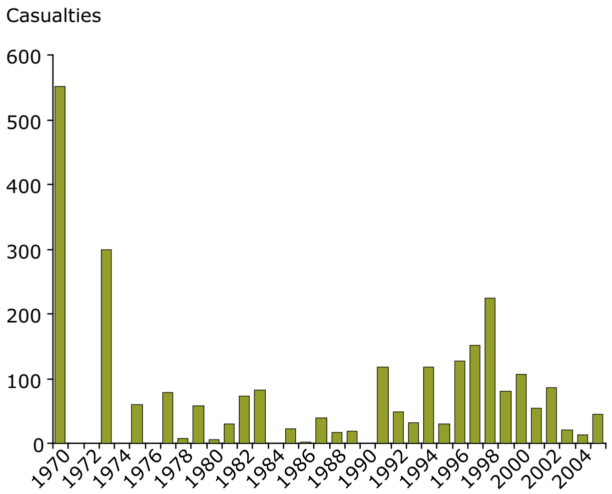
Source: Barredo, 2007.

Relevance

There is good reason to be concerned about the growth of flood losses in Europe even without taking climate change into account. Economic losses from flood disasters in Europe increased from the 1970s to the 2000s (Barredo, 2007). In addition to the rising trend in flood damage, the effects of unusually severe floods during the 1990s and 2000s increased awareness of the economic consequences of flooding. The 1997 floods in Poland and Czech Republic were responsible for losses of about EUR 5.2 billion. In 2000, Italy, France and Switzerland experienced losses of EUR 9.2 billion. In 2002 the material flood damage of EUR 17.4 billion recorded in Germany, the Czech Republic and Austria was higher than in any single previous year (Kundzewicz *et al.*, 2005). And the cost of floods in the United Kingdom in summer 2007 has been estimated at around EUR 4.3 billion.

There is no clear evidence of a climate-related trend for floods during recent decades in Europe (Mudelsee *et al.*, 2003; Kundzewicz, 2005). Even

Figure 7.6 Number of casualties caused by flood disasters in the EU 1970–2005



Source: Barredo, 2007.

([14]) Flood disasters are defined here as extreme flood events associated with actual damage (i.e. an extreme flood event in an unpopulated area may create no damage).

if there is scientific evidence of a continuing intensification of the global water cycle (Huntington, 2006) there is no homogeneous trend in extreme river flows on the European or regional scale. Analyses of long-term records of flood losses indicate that societal and economic factors have played an important role in the observed upward trends (Pielke Jr and Downton, 2000; Mills, 2005; Barredo, 2007).

Past trends

Flood disasters in Europe increased in number and amount of loss from the 1970s to the 2000s. The number of major flood disasters during the last 16 years (between 1990 and 2005) is more than twice that between 1970 and 1989 (Barredo, 2007, see also Section 5.5.3). When assessing flood losses it is important to compensate for changes in asset values and exposure over time. Failure to adjust for economic factors results in loss amounts that are not directly comparable over time and a pronounced ever-increasing trend for purely economic reasons (Höppe and Pielke Jr, 2006; Muir Wood *et al.*, 2006). Figure 7.5 therefore shows the costs of flood losses in Europe as a percentage of GDP ([15]). A continuous increase is observed in the decadal average of flood damage expressed in this way.

In fact in the period 1970–1999 the trend in EU flood losses was not statistically significant, and the increase registered in the last sub-period is a consequence of one single event, the floods in central Europe in the summer of 2002. However, even though evidence indicates that the growth of flood losses in recent decades is related to both societal and climatic factors, the shares are unclear (Pielke Jr and Downton, 2000; Barredo, 2007). It is therefore still not possible to determine the proportion of the increase in damage that might be attributed either to climate change or to societal change and economic development (Höppe and Pielke Jr, 2006). There is agreement that climate change cannot be regarded as the dominant factor for increasing flood losses. In addition there are no conclusive studies that confirm the hypothesis of changes in the occurrence of extreme river flows in Europe. In a hypothetical scenario without climate change, total flood losses will continue to increase as consequence of societal and economic factors such as increase in exposure and vulnerability (Pielke Jr and Downton, 2000).

Figure 7.6 shows the yearly number of deaths resulting from floods in Europe for the period 1970–2005. There is no clear trend. The number of deaths is very dependent on single events, as for the events of 1970 in Romania and Hungary, 1973 in Spain, and 1998 in Italy. In recent decades, early warning systems and prevention measures have improved evacuation mechanisms in the many areas exposed to floods.

The issue of extreme precipitation and surface water flooding (heavy rainfall and insufficient capacity of drainage systems) is also worth further investigation since this is already causing problems while not being well enough understood in terms of risk mapping. It has been estimated that the 2007 summer floods in the United Kingdom were caused mainly by surface water flooding and inadequate drainage (roughly 60 % of the losses) while the rest was caused by river flooding.

Projections

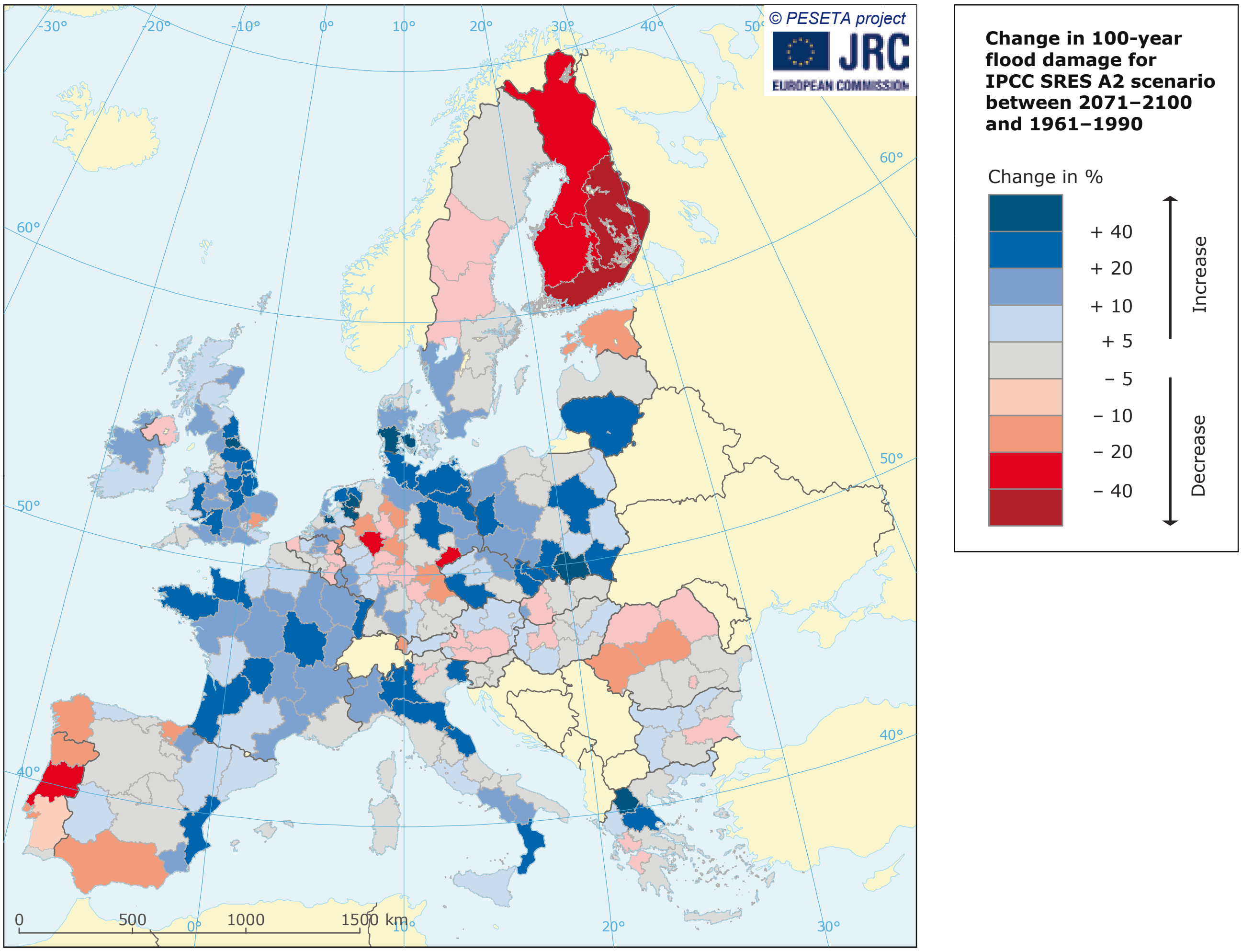
Some preliminary estimates (ABI, 2005) indicate that annual flood losses in Europe could rise to EUR 100–120 billion (tenfold) by the end of the century under high emissions scenarios. Hall *et al.* (2005) presented a national-scale assessment for England and Wales, and predicted an up to 20-fold increase in losses by the 2080s in the scenario with the highest economic growth and no adaptation. These results include changes in sea-level rise, increasing precipitation and increasing economic vulnerability. More detailed disaggregated work under the PESETA project ([16]) has modelled changes in river flows in a changing climate in Europe, studying two river catchments in detail.

- For the Upper Danube the estimated total damage of a 100-year flood is projected to increase by 2100 by around 40 % of the current damage estimate (an increase of EUR 18.5 billion) for the high emission scenario (A2) and around 19 % for the intermediate emission scenario (B2). The number of people affected is projected to increase by 242 000 (around 11 %) for the A2, and 135 000 (around 6 %) for the B2 scenario.

- For the Meuse, the potential damage of a 100-year flood is projected to increase by about 14 % for the A2 scenario and about 11 % for the B2 scenario.

([15]) GDP has been used as surrogate measure of exposure since other direct measures are not available for all the assessed countries.
([16]) In the rest of this chapter some of the preliminary results of the PESETA project on the effects of climate change in Europe will be presented. PESETA is a JRC-funded project, coordinated by IPTS, and benefitting from past DG Research projects. All results relate to the same scenario (unless otherwise stated): A2 SRES socio-economic driver, HadAM3H Global Circulation model, HIRHAM Regional Climate Model. The PESETA project also considers other scenarios derived from different socio-economic drivers and different climate models (see http://peseta.jrc.ec.europa.eu/). For river floods, see http://peseta.jrc.ec.europa.eu/docs/Riverfloods.html.

Map 7.2 **Projected change in damage of river floods with a 100-year return period between 2071–2100 and 1961–1990**



Note: Model calculation using the IPCC SRES scenario A2 and NUTS2 level.

Source: JRC PESETA project (http://peseta.jrc.ec.europa.eu/docs/Riverfloods.html).

These regional studies have been expanded for river flooding EU-wide. Map 7.2 shows the percentage change in economic damage for floods with 100-year return period for the SRES A2 scenario.

A number of uncertainties in these river catchment and Europe-wide results should, however, be highlighted. First, the numbers are the combined effect of the climate and socio-economic effects, and second, they do not include existing or any future flood protection and management measures ([17]), so strictly speaking they are a measure of potential exposure, not impacts (though they may underestimate potential losses by not incorporating changes in exposure). This highlights a broad issue with climate and socio-economic analysis of future flood risks. Research into flood risks in the Netherlands indicates that potential economic losses from flooding (river and sea) as a result of socio-economic change could increase by 22–45 % in 2040 (WL Delft Hydraulics, 2007). The particular role of climate change was not taken into account, because of unknown effects on flood severity and frequency. Moreover, socio-economic factors are expected to dominate future loss records, and will continue to complicate normalisation studies, because of the large inaccuracies associated with actual loss estimates, compared with geophysical data on extreme weather itself (Pielke Jr, 2007).

([17]) There are no datasets available for existing measures for the whole of Europe, so these are not considered in the assessment.

7.4 Coastal areas

Key messages

- Coastal flooding can lead to important losses. By 2100, the population in the main coastal European cities exposed to sea-level rise and associated impacts on coastal systems is expected to be about 4 million and the exposed assets more than EUR 2 trillion (without adaptation).
- Future projections of sea-level rise and associated impacts on coastal systems show potentially large increases in the risk of coastal flooding. These could have signficant economic costs (without adaptation), with recent estimates in the range of 12 to 18 billion EUR/year for Europe in 2080 under the IPCC SRES A2 scenario. The same estimates indicate that adaptation could significantly reduce this risk to around EUR 1 billion.

Climate change is an additional pressure and, as shown by the PESETA project on the effects of climate change on European coastal systems, is likely to have significant impacts on coastal zones, particularly through sea-level rise and changes in the frequency and/or intensity of extreme weather events, such as storms and associated surges. Coastal zones in Europe contain large human populations and significant socio-economic activities. They also support diverse ecosystems that provide important habitats and sources of food. One third of the EU population is estimated to live within 50 km of the coast, and some 140 000 km^2 of land is currently within 1 m of sea level. Significantly inhabited coastal areas in countries such as the Netherlands, England, Denmark, Germany and Italy are already below normal high-tide levels, and more extensive areas are prone to flooding from storm surges.

There are estimates of the physical impacts and economic costs to coasts in Europe from sea-level rise and flooding storm events. Results using the DIVA database and model produced from the DINAS-COASTS DG research project (DINAS-COAST Consortium) have been developed for Europe in the PESETA project ([18]). They show impacts increasing significantly without adaptation: in the 2080s under the A2 SRES scenario, it is estimated that around 2 000 to 17 000 km^2 of land in Europe could be permanently lost, leading to 0.1 to 1.3 million people in Europe experiencing coastal flooding each year, depending on the climate sensitivity. The economic costs of these events are estimated in the range of 12 to 18 billion euro/year for Europe in 2080 (current prices) ([19]). Large areas of coastal wetlands are also threatened, with the highest relative losses on the Mediterranean and Baltic coasts.

ABI (2006) estimates that a 40 cm rise in sea levels will put an extra 130 000 properties at risk of flooding in the United Kingdom. In total 400 000 properties will be at risk, up nearly 50 % on the current number. Without improvements to existing flood defences, the costs of a major coastal flood could soar by 400 % to as much as GBP 16 billion. Essential services and lives will also be at risk, e.g. 15 % of fire and ambulance stations and 12 % of hospitals and schools are in flood-risk areas. The elderly will be particularly affected as the number living on, or moving to, the coast is well above the national average.

Using the same climate and sea-level projection as above (A2 scenario in the 2080s), with hard adaptation measures (dike building and beach nourishment) included, the DINAS-COAST Consortium and the PESETA project suggest that the land loss falls to less than 1 000 km^2 and the economic costs to around 1 billion euro/year. The adapation costs (mainly coast protection with dikes) are estimated at some 1 billion euro/year, but these achieve considerable reductions in the residual damage.

ABI (2006) also estimates that spending around GBP 6–8.5 billion on improving coastal defences would have a substantial impact on damages, both now and in the future. In other words, they would virtually pay for themselves in a single incident, ignoring the wider social and economic costs that arise from regional damage. But of course sea

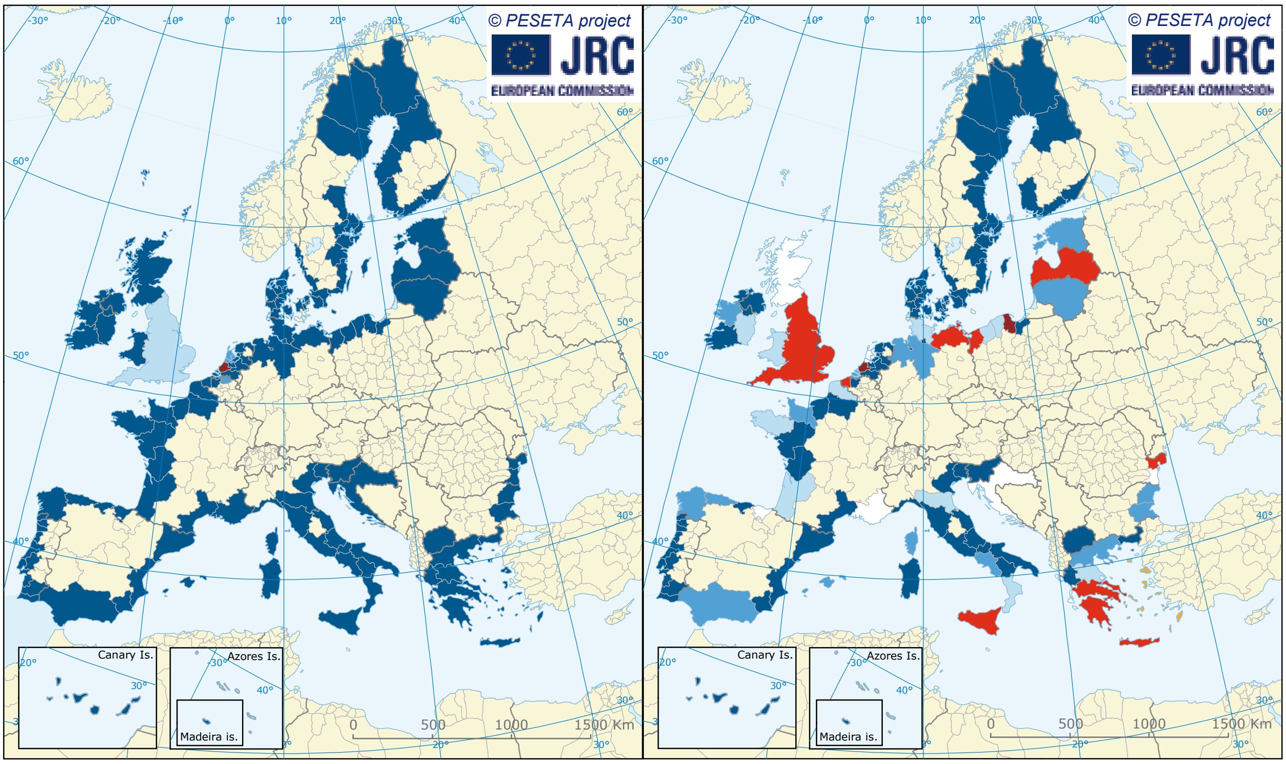
([18]) See http://peseta.jrc.ec.europa.eu/docs/Costalareas.html.
([19]) This includes the combined effect of climate and future socio-economic developments.

defences do not simply operate on a single occasion: in reality defences would prevent many less severe storm surges from causing damage. Typically this type of capital investment may deliver benefits over its lifetime worth seven times the cost. The benefits from this investment will be even greater if the frequency of storms increases in line with predictions.

However, there are many possible adapation measures that can minimise the impacts of sea-level rise and would have significant benefits (including soft measures) such as: coastal defences (e.g. physical barriers to flooding and coastal erosion such as dikes and flood barriers); realignment of coastal defences landwards; abandonment (managed or unmanaged); measures to reduce the energy of near-shore waves and currents; coastal morphological management; and resilience-building strategies. Despite some difficulties in estimation, there is an increasing literature reporting the direct costs of adaptation to sea-level rise and estimating optimal levels of protection based on cost-benefit analysis.

Recent work (OECD, 2008) has also looked at threats to current and future major coastal cities from sea-level rise (0.5 metres global average) and storm surges. It assessed exposure to a 1 in 100 year flood event, looking at population and asset value exposed now and with sea-level rise in 2100 for the following cities: Amsterdam, Rotterdam, Hamburg, London, Copenhagen, Helsinki, Marseille-Aix-en-Provence, Athens, Napoli, Lisbon, Porto, Barcelona, Stockholm, and Glasgow. For these cities, the exposed population increases from 2.3 million to 4.0 million, and the exposed assets from EUR 240 to EUR 1 400 billion (the values are dominated by London, Amsterdam, and Rotterdam).

Map 7.3 **Modelled number of people flooded across Europe's coastal areas in 1961–1990 and in the 2080s**



People flooded (thousands/year) across Europe (coastal areas)

Left: Baseline (1961–1990)

≤ 2 > 2 > 4 > 6 > 8 > 10 > 12

Right: IPCC SRES A2 scenario, 2080s (ECHAM4), without adaptation

< 2 2 4 6 8 10 50 150

Source: JRC PESETA project (http://peseta.jrc.ec.europa.eu/docs/Costalareas.html).

7.5 Public water supply and drinking water management

Key messages

- Economic consequences of climate change impacts will be particularly pronounced in areas where increases in water stress are projected. Evaluation studies of the economic consequences of increasing water stress are now emerging. They indicate that adaptation costs are generally significantly lower than the losses that would be incurred without adaptation.

Changes in water demand depend strongly on economic and sectoral growth and societal developments. Household water demand is likely to increase with climate change, with more water used for garden watering and personal hygiene, although a clear separation exists between components that are sensitive to climate change (showering, gardening, lawn sprinkling, golf courses, swimming pools and aqua parks), from those that are non-sensitive (e.g. dish washing, clothes washing). Changes in the quantity and quality of river flows and groundwater recharge may affect drinking water supply systems and alter the reliability of raw water sources (see Chapter 5 for details).

Problems of water supply in islands and tourist resorts are becoming increasingly common, e.g. Cyprus is exploring the possibilities of transporting water in tankers from Lebanon. Hot summers such as 2003 and 2007 may provide an indication of future climate impacts on peak water demand (e.g. 15 % increase in public demand in the Netherlands in August 2003; state of emergency declared on the Cyclades islands in Greece in summer 2007 and reservoirs down to less than 5 % full in Turkey's capital (Ankara, home to 4 million´people)). Other studies, however, indicate that the increase in household water demand may be rather small. Downing *et al.* (2003) concluded that per capita domestic demand in England could rise by an extra 2 to 5 % during the next 20 to 50 years as a result of climate change.

High water temperatures, low water flows and therefore less dilution of pollutants may have severe consequences on the quality of drinking water and recreation activities related to water. Saline intrusion in coastal aquifers making the water unsuitable for drinking water may be exacerbated by future sea-level rise.

These effects have economic consequences, especially in areas where there are predicted increases in water stress. Alcamo *et al.* (2007) project that the percentage of land area under high water stress in Europe is likely to increase from 19 % today to 35 % by the 2070s, and the additional number of people affected is expected to be between 16 and 44 million. Some studies on the economic consequences of increasing water stress are emerging. Work in the United Kingdom has estimated the economic losses to households of foregone water use due to the anticipated water deficit by 2100 in south-east England at between GBP 41 and GBP 388 million per year (depending on the scenario). However, the costs of adaptation to largely (but not entirely) eliminate these deficits would be only GBP 6 to GBP 39 million per year.

7.6 Agriculture and forestry

Key messages

- The hot summer of 2003 in Europe is estimated to have led to EUR 10 billion in economic losses to farming, livestock and forestry from the combined effects of drought, heat stress and fire.
- Climate-related increases in crop yields are expected mainly in northern Europe (by about 10 %) with reductions (of 10 % or more) in the Mediterranean and the south-west Balkans.
- There are likely to be changes in forest growth with climate change, and related economic consequences, though projections of future net changes in Europe are uncertain.

Agriculture

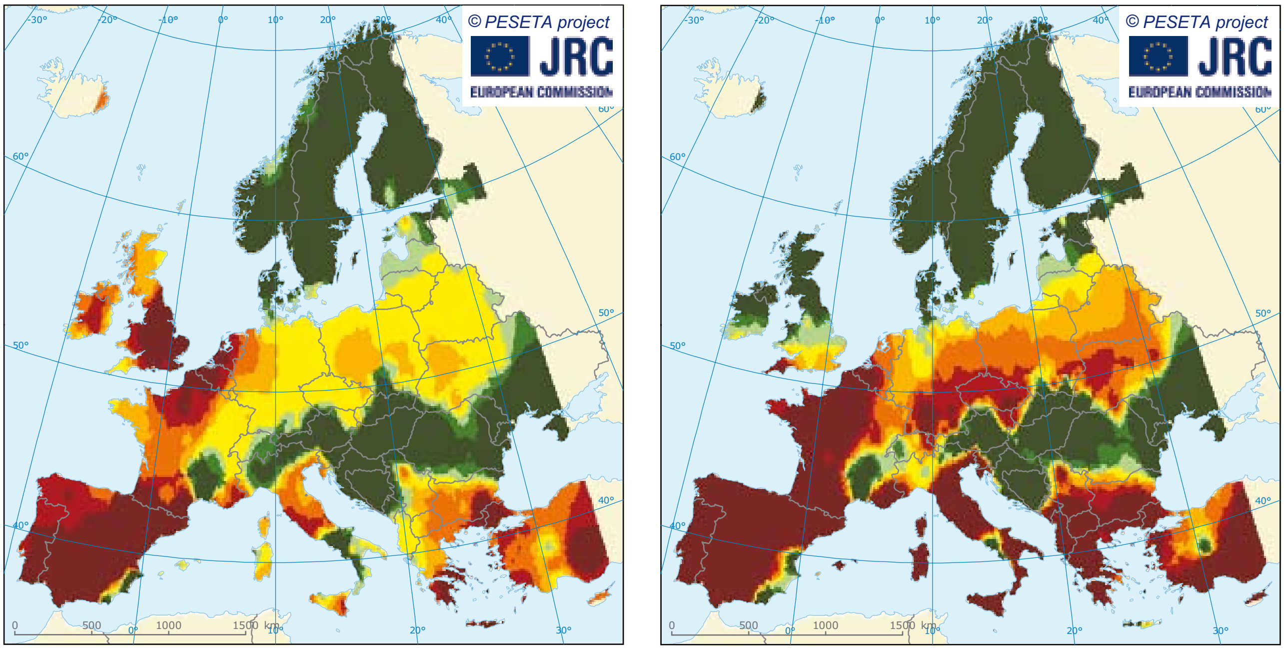
Agriculture accounts for only a small part of gross domestic production (GDP) in Europe, and it is considered that the overall vulnerability of the European economy to changes that affect agriculture is low (EEA, 2006). However, agriculture is much more important in terms of area occupied (farmland and forest land cover approximately 90 % of the EU's land surface), and rural population and income. The agriculture sector has a strong influence on other sectors, and, moreover, the effects of climate change may still be substantial at the European level because of the spatial distribution of changes. The overall economic indicators are related partly to total yield and market prices, as well as to many other factors (e.g. subsidies, labour and production costs, global price changes, efficiency and productivity, technological development, consumer demand, socio-economic development) ([20]). Hence climate change is only one driver among many that will shape agriculture and rural areas in future decades. Socio-economic factors and technological developments will need to be considered alongside agro-climatic changes to determine future trends in the sector. In this respect, most projections of long-term impacts on yields do not fully consider technological progress and adaptation.

Agriculture is a more significant sector in southern European (Mediterranean) and southerly eastern European countries in terms of employment and GDP, and these countries will face greater stresses due to climate change that will lead to lower yields. A loss in agricultural potential would therefore impose a larger income loss in these regions than over the rest Europe. In contrast, the agricultural systems in western Europe are considered to have lower sensitivity to climate change, and modelling predictions show likely opportunities in terms of yield increases and wider agricultural crops for northern Europe. The recent IPCC 4th assessment report (2007b) concludes that in northern Europe, climate change is initially projected to bring mixed effects, including some benefits such as increased crop yields and increased forest growth. However, as climate change continues, its negative impacts are likely to outweigh its benefits.

Most of the analyses now build in (autonomous) adaptation, reflecting a likely trend of producers to alter practices and crop types by region as the climate changes. Several studies show the likely spatial patterns outlined above, with a strong distribution of yield changes across Europe, as found in the recent PESETA project ([21]), which has projections for regional yield changes for the 2080s. It shows that south and west Europe could experience a decrease in yields of 10 % or more (due among others to shortening of the growing season), though there are also improvements of yields in Nordic countries (increase in growing season, but also higher minimum temperatures in winter). The general decreases in yields in southern Europe will be combined with increases in water demand. Recent valuation studies in the United Kingdom predict increases in yields and also revenue in the 2020s, but with these declining by the 2050s and expected economic losses of up to GBP 24 million/year by the 2080s, particularly in more southern areas where water becomes increasingly limited.

([20]) There are currently no detailed data available on subsidy distribution by crop and region.
([21]) See http://peseta.jrc.ec.europa.eu/docs/Agriculture.html.

Map 7.4 Projected crop yield changes between the 2080s and the reference period 1961–1990 by two different models



Simulated crop yield changes by 2080s relative to the period 1961–1990 under the HadCM3/HIRHAM (left) and ECHAM4/RCA3 (right) A2 scenario

Change in %

– 30 – 15 – 10 – 5 0 5 10 15 30

Note: Model calculations using a high emission scenario (IPCC A2) and two different climate models: HadCM3/HIRHAM (left), ECHAM4/RCA3 (right).

Source: JRC PESETA project (http://peseta.jrc.ec.europa.eu/docs/Agriculture.html).

However, while these models generally consider the effects of projected changes in temperature and CO_2 fertilisation, they do not fully consider issues of water availability, and rarely consider extreme events. The latter could be important for Europe in relation to heat extremes and floods. As an example, the droughts of 1999 caused losses of more than EUR 3 billion in Spain (EEA, 2004) and the hot summer of 2003 in Europe is estimated to have led to EUR 10 billion in economic losses to farming, livestock and forestry from the combined effects of drought, heat stress and fire (Munich Re, 2008) ([22]). A proactive risk management and insurance scheme will therefore be vital to European agriculture in the near future. A major paradigm shift will also be required in order to incentivise autonomous and planned adaptation.

Finally, the role of autonomous and planned adaptation is extremely important for agriculture, and this has been studied intensively. While most analyses consider short-term autonomous adaptation, there are also potential long-term adaptations in the form of major structural changes and technological progress to overcome adversity caused by climate change, which are usually the result of a planned strategy. There are a number of studies that show the benefits of adaptation to farmers in reducing negative impacts, although the costs of adaptation are rarely made explicit.

A recent study commissioned by the EC (DG AGRI) on 'Adaptation to Climate Change in the Agricultural Sector' and undertaken by AEA-T and the Universidad de Politécnica de Madrid,

([22]) Overall net positive effects on the UK agricultural, fruit and viticulture industries are also estimated to have occurred with estimated economic benefits of GBP 64 million. However, the authors note that it is not possible to conclude with any confidence that these gains/losses are wholly attributable to the weather conditions that prevailed in the summer of 2003.

analysed potential impacts, risks and opportunities as well as adaptation options for EU agriculture (EC, 2007). It indicates for example that the prolonged drought in Finland in 2002/2003 caused estimated losses of EUR 100 million compared with normal years. Water had to be transported by tanker to more than 1 100 farms (Martilla *et al.*, 2005). In addition, it reports recent research activities such as that undertaken by the Latvian State Institute of Agrarian Economics on an agricultural insurance system.

Potential economic effects on agriculture beyond cereals yields are also key issues. The expected increase in climate variability (extreme events) could trigger variability in agricultural production, food prices and farm income as the frequency of crop failures increases. Year–to-year weather variability is the main determinant of yield levels, which determine prices and the inherent risks of farming.

Forestry

Forestry is also a small part of European GDP, although in a large part of Europe it represents an important economic sector and also provides potential for carbon sequestration and environmental services. Forests in Europe are likely to be affected by climate change, in terms of distribution (forest area will expand in the north, but contract in the south), species composition, forest yield, windstorm damage and forest fires (Alcamo *et al.*, 2007, Eurostat Pocketbooks — Forestry statistics 2007 edition). Potential economic consequences of forest fires (i.e. enlargement of the fire-prone area and a lengthening of the fire season) include lost production and direct costs of fire fighting. In the summer 2003 heat wave in France, the costs of fighting forest fires for the Ministry of Interior increased from EUR 83 million in a normal year to EUR 179 million.

An on-going study commissioned by the EC (DG AGRI) on the 'Impacts of climate change on European forests and options for adaptation' led by the European Forest Institute (EFI), analyses in depth exposure, sensitivity, potential impacts, adaptive capacity and vulnerability in relation to European forests as well adaptation options (EC, 2008a). It indicates that forest damage by wind and snow is a continuing cause of economic loss in forestry throughout Europe. The economic cost of the damage corresponds approximately to hundreds of millions of US dollars each year. 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. For example, in Sweden, approximately 4 million m^3 of timber is damaged annually by snow and wind, roughly corresponding to EUR 100 million.

While the economic effects of timber production can be captured using market prices, forests (natural and managed) play a much greater role than timber alone, and there is a need to progress towards a total economic valuation of forestry including full ecosystem goods and services.

7.7 Biodiversity and ecosystem goods and services

Key messages

- Work undertaken under Phase I of the joint initiative 'The Economics of Ecosystems and Biodiversity' tentatively indicates that the cumulative welfare losses due to loss of ecosystem services could be equivalent to 7 % of annual consumption by 2050. This damage calculation captures a number of causes for biodiversity loss, including climate change as one of the pressures. However, little is currently known either ecologically or economically about the impacts of future biodiversity loss, and further assessment and methodological work is needed.
- Methods for the valuation of ecosystems are improving, but it is not yet possible to cover a wide range of ecosystem productivity, goods and services, or the economic benefits to direct and indirect users.

The functioning of ecosystem service provision by many natural and semi-natural ecosystems in Europe is under threat from land use change and other pressures, including climate change. Such services include food and water supply, climate regulation and species preservation. Particularly sensitive areas include the Arctic region, mountains, and various coastal zones, especially in the Baltic and parts of the Mediterranean. The ecosystem services can be divided into supporting, provisioning, regulating and cultural. Most functions attributed to provisioning services have a direct market value e.g. food, fish, timber and fresh water. Other functions, such as regulating and cultural services and the ability of an ecosystem to provide natural habitat for flora and fauna, and biodiversity have, however, no direct market price, though it is possible in some cases to approximate the value of these.

Past and ongoing research tries to value ecosystem loss, reflecting ecosystem productivity, goods and services, but also the wider use of ecosystems, increasingly using the Millennium Ecosystem Assessment framework (MEA, 2005). This uses the rate of extinction (per thousand species per millennium) to illustrate some of the changes in ecosystem services. There is also a growing body of more general economic studies on ecosystems and biodiversity, and of work studying places where biodiversity loss has led to the loss/degradation of ecosystem services and consequently to economic costs. However, while methods for valuation of ecosystems are improving, as yet they fail to cover the full range of ecosystem productivity, goods and services, and direct and indirect economic benefits to users. Nonetheless, there are some illustrative values showing potentially very high estimates (e.g. IPCC, 2007b). Hence, at this stage it is extremely difficult to put forward indicators for the economic effects on ecosystems associated with climate change.

Following commitments made at the G8+5 meeting of Environment Ministers in Potsdam in March 2007, a joint initiative has been launched to draw attention to the global economic benefits of biodiversity and the costs of biodiversity loss and ecosystem degradation, entitled 'The Economics of Ecosystems and Biodiversity' (TEEB). The initiative will evaluate the costs of the loss of biodiversity and the associated decline in ecosystem services worldwide. It will consider the failure to take protective measures vs. the costs of effective conservation and sustainable use, and provide a better understanding of how action to halt the loss of biodiversity makes economic sense. The interim report (EC, 2008b), which gives the results of Phase I of the initiative, was presented at the high-level segment of the 9th Conference of the Parties (COP9; May 2008) to the UN Convention on Biological Diversity (CBD) whose aim is to significantly reduce the loss of biodiversity by 2010. Work undertaken under Phase I of TEEB tentatively indicates that the cumulative welfare losses ([23]) due to loss of ecosystem services could be equivalent to 7 % of annual consumption by 2050 ([24]). This damage calculation captures a number of causes for biodiversity loss, including climate change as one of the pressures.

The study therefore showed that the problem is potentially severe and economically significant, but that we know relatively little both ecologically and economically about the impacts of future biodiversity loss. Further work is envisaged in Phase II of the joint initiative, also to further elaborate the assessment framework and the methodology.

([23]) This is calculated as a welfare loss and not a GDP loss since a large part of ecosystem services is currently not included in GDP.
([24]) This is a conservative estimate. For details see EC, 2008b.

7.8 Energy

Key messages

- Historic 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, although country-specific data show some increases in cooling degree days over the same period, consistent with greater space-cooling demand.
- Future 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 strong distributional patterns, with significantly reduced space-heating demand in northern Europe and increased space-cooling demand in southern Europe, with associated costs and benefits. There may also be increases in energy demand associated with adaptation to climate change, e.g. for water supply.
- 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 possibly natural hazards.
- Climate change could have an adverse impact on thermal power production as most studies show that summer droughts will be more severe, hence limiting the availability of cooling water in terms of quantity, appropriate temperature and power plant efficiency.

Heating and cooling demand

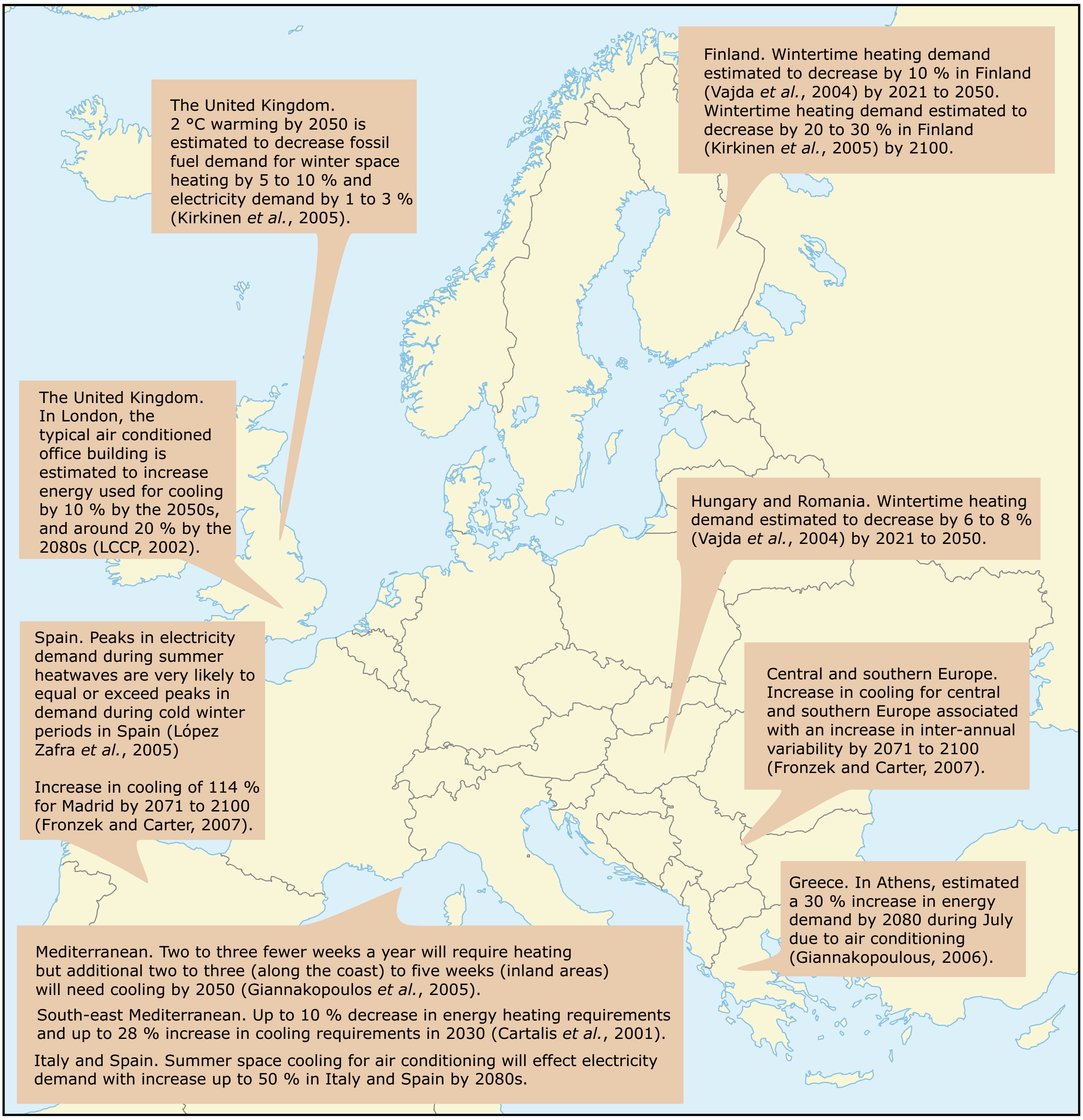
Energy industries are the single most important source of greenhouse gas emissions in Europe and will also be affected by climate change. Numerous studies have demonstrated that energy demand is linked to climatic conditions (e.g. outside temperature), particularly in the domestic sector, but also in the service and industry sectors (Eurostat, 2007). The changing climate in Europe is likely to lead to a decrease in demand for winter heating, but an increase in summer cooling, which can be described as either an impact or an adaptation measure that in some cases can offset mitigation efforts. There are also other factors that affect the apparent temperature and the related energy demand such as wind chill, illumination and cloud cover, and precipitation.

Energy demand has risen very strongly in Europe over recent years, due to technical, behavioural and socio-economic factors (Eurostat, 2007). Actual final energy consumption for heating since 1997 has been persistently below the projected temperature-corrected consumption. This suggests warmer-than-average years at the European level, which is confirmed by the information on heating degree-days. The heating degree days (HDD) data show that recent years (since 1996) are all lower than the long-term average ([25]). Note that at present, net energy demand in Europe is dominated by space heating rather than cooling. However, it is difficult to separate (or 'normalise') the specific effect of outside temperature from these data from technical, behavioural and socio-economic factors ([26]). The heating degree day indicator above shows a falling trend reflecting the recent warmer years, translating into a lower winter heating burden (a benefit). There is currently less data available on space cooling demand at the European level, which relates to human comfort levels, but also cooling for appliances.

Projections for Europe suggest further reductions in heating degree days, and further increases in cooling degree days, due to mean average temperature

([25]) The relative degree days are weighted by population or area. The HDD figures for individual European countries vary considerably, with much higher HDD values for Scandinavian countries, and much lower ones for southern European countries, though there is a downward trend across both regions.
([26]) For example the effects of population, housing density, housing stock, insulation levels, technology, equipment penetration level, efficiency of heating or cooling units, behaviour, perceived comfort levels, energy prices, income.

Map 7.5 Projections of energy demand for several time horizons in Europe

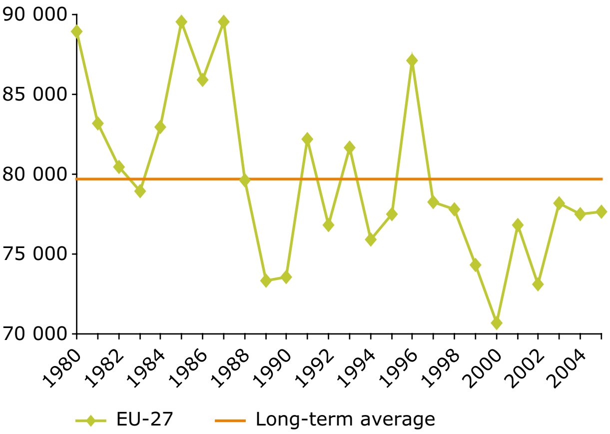


Source: Alcamo *et al.*, 2007.

increases. For cooling, there may be additional peaks associated with heat waves. The overall changes in energy and economic costs (at a net level) are predicted to be modest in the short-medium term, due to the aggregated effects of decreased winter heating demand vs. increased summer cooling demand. However, strong distributional patterns are expected across Europe — with rising cooling (electricity) demand in summer in southern Europe, compared with reduced heating (energy) demand in winter in northern Europe (Alcamo *et al.*, 2007; see Map 7.5). This translates into a likely net benefit to northern Europe and net losses for southern Europe.

The actual net economic costs are more complex to estimate, due to interactions between energy sources, technology, socio-economic trends and future mitigation scenarios. Winter heating demand is primarily from fossil-fuel use, and summer cooling from electricity, and there may be additional issues

Figure 7.7 Heating degree days in Europe 1980–2005



Source: Eurostat (http://epp.eurostat.ec.europa.eu/cache/ITY_SDDS/EN/nrg_esdgr_sm1.htm) and JRC (JRC IPSC/Agrifish Unit/MARS-STAT Action).

of peak demand levels in southern Europe in the summer ([27]). Adaptation has a role to play here, particularly through alternatives to mechanical air conditioning, e.g. through passive ventilation, building design and planning; synergies between mitigation and adaptation are important to consider in this context. Finally, there may also be an emerging issue of energy use for water supply increasing (pumping, desalinisation, recycling, irrigation, water transfers). Again, these are likely to be greater in southern Europe where overall precipitation levels are projected to fall. There is also the potential for extreme weather events (e.g. storms) to increase the risk of energy infrastructure failure.

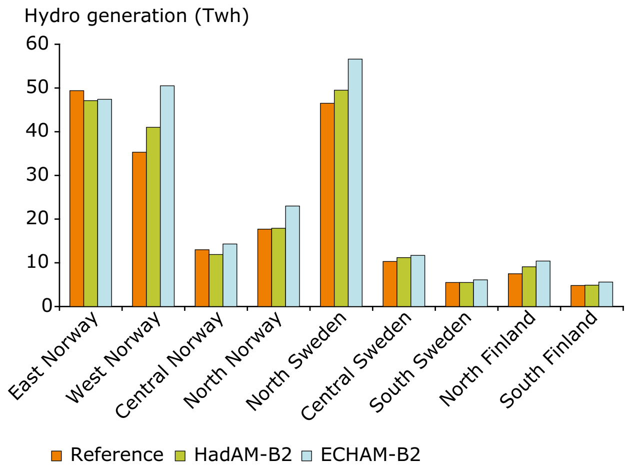
Hydropower and cooling water for thermal plants

The production of electricity is strongly dependent on water, both for cooling in power plants and for hydropower ([28]). In some areas, hydropower may benefit from increased river runoff, while in others this potential will decrease (see Section 5.5 for details). The generation of electric power in thermal (in particular coal-fired and nuclear) power stations often relies on large volumes of water for cooling. During heat waves and drought periods the use of cooling water may be restricted if limit values for temperature are exceeded, which may force plant operators to work at reduced capacity or even temporarily close down, with potentially serious consequences.

Since the 1970s, annual energy production of some existing hydropower stations in Europe has decreased, in particular in Portugal, Spain and other southern European countries (UCTE, 1999). This has been attributed to changes in average discharge, but whether this is due to temporary fluctuations or are already the consequences of long-term changing climate conditions is not yet known (Lehner *et al.*, 2001). Dam and reservoir safety may be affected under changed climatic conditions by more frequent extreme flows. However, evaluating changes in reservoir safety is complex (Veijalainen and Vehviläinen 2006; Andréasson *et al.*, 2006).

The EuroWasser study (Lehner *et al.* 2001, 2005) demonstrates a clear north-south gradient. Although there are large local differences between the outcomes for the two models used (ECHAM4 and HadCM3), especially in the Alps and part of the Mediterranean region, both show increases in hydropower production up to 25 % or more in north Europe, and reductions by 25 % or more in southern parts by 2070.

Figure 7.8 Projected changes in hydropower production in Scandinavia



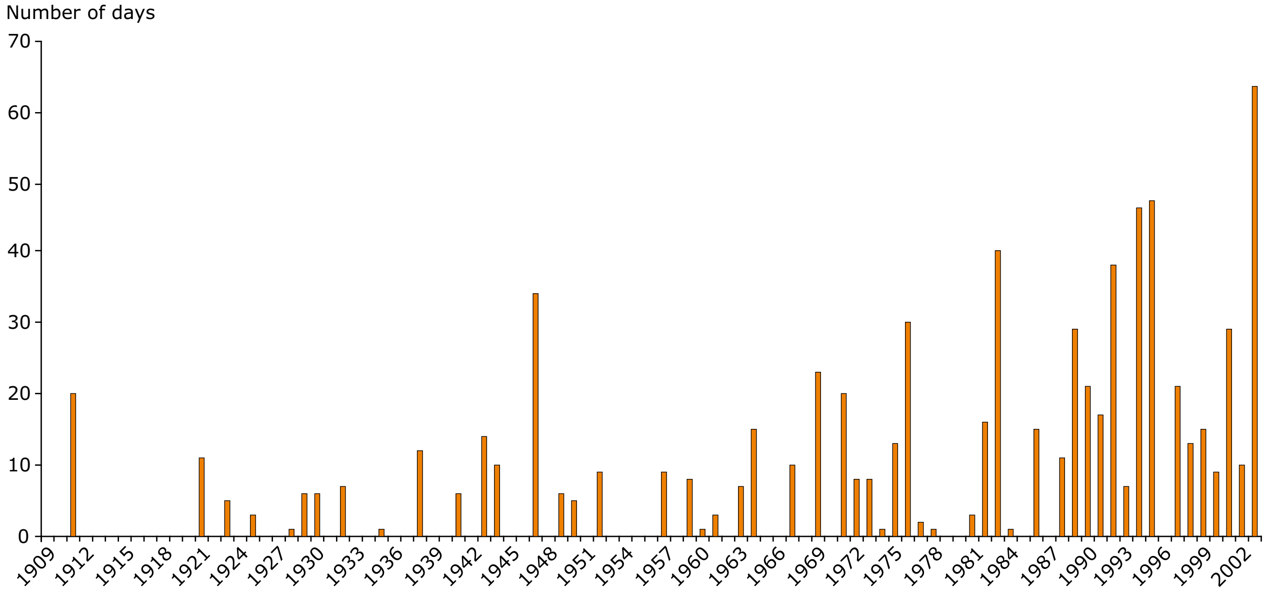
Note: Reference period 1961–1990, projections for 2071–2100 for two models (HadAM and ECHAM) and IPCC SRES scenario B2.

Source: Mo *et al.*, 2006.

([27]) While the overall energy balance may not change that greatly in Europe as a result of climate change, there could still be important economic effects. Winter space heating is provided by fuels (coal, oil, gas) that can be stored. Summer cooling is provided by electricity, which cannot be stored easily. A rise in peak summer electricity demand, associated with cooling and heat waves in southern Europe, could increase the plant peak capacity needed, which would be expected to lead to higher marginal costs.

([28]) In 2005 hydropower contributed 9.25 % of the electricity consumption in the EU-27 (Eurostat energy balances). The share of hydropower in the electricity production is usually high in the northern countries and countries in the Alps. In 2001, the EU agreed that 21 % of the total electricity consumption in 2010 should come from renewable resources (EU, 2006). In 2005, the share of renewable energy sources in gross electricity consumption was 14 %, of which hydropower represented 66 % (Eurostat energy balances).

Figure 7.9 Number of days with water temperature higher than 23 °C in the river Rhine (Lobith, the Netherlands) 1909–2003



Source: Bresser *et al.*, 2006.

The Nordic Climate and Energy study (covering Scandinavia, Iceland and the Baltic states; Bergström *et al.*, 2007) also projects increases in hydropower production in Scandinavia in more detail due to the use of RCMs (Regional Circulation Models) for downscaling. Generally the increase is largest in the western coastal regions. Figure 7.8 shows the hydropower production by regions for the reference period 1961–1990 and for 2070–2100 for two models. Decreased precipitation is expected to have an adverse impact on the electricity generation sector where rivers provide the cooling water. Power stations have to be shut down when water temperatures exceed ([29]) or river levels fall below certain thresholds (see Figure 7.8). Electricity production has already been significantly reduced in various locations in Europe during very warm summers, such as in 2003, 2005 and 2006 (BMU, 2007; Lehner *et al.*, 2005). It is highly likely that electricity companies will experience greater problems with their cooling water systems due to the rise in temperature and more frequent low discharges.

([29]) Cooling water discharge must be no warmer than 30 °C; a water temperature of 23 °C applies as the critical limit for the intake of cooling water.

7.9 Tourism and recreation

Key messages

- Changes in climate are starting to impact upon the attractiveness of many of the Mediterranean's major resorts, while improving it in other regions.
- Future projections of climate change suggest that the suitability of the Mediterranean for tourism will decline during the key summer months, though there will be an increase during other seasons (spring and autumn). This can produce shifts in the major flows of tourism within the EU, which will be very important in regions where tourism is a dominant economic sector, though adaptation responses such as economic diversification will be critical to limit economic losses. The tourism industry will therefore face significant adaptation costs.
- Adaptation measures will be driven by climate change and socio-economic factors, and their sustainability (e.g. associated environmental impacts) will have to be assessed. Mal-adaptation should be avoided and adaptation measures will also have to be developed in synergy with mitigation actions.

As shown by the PESETA project, which studied the effects of climate change on European tourism, mass tourism is closely associated with climate, for both the source of tourists and their destination. At present, the predominant summer tourist flows are from north to south, to the coastal zone. However, coastal and mountain tourism are the segments that are most vulnerable to climate change, and the Mediterranean region is the world's most popular holiday region: it attracts some 120 million visitors from northern Europe each year, the largest international flow of tourists on the globe, and their spending is in excess of EUR 100 billion. There are large differences within Europe and between seasons as to attractiveness for tourism. During the key summer months the Mediterranean has a 'close-to-ideal' climate for tourism, with very high values of the Tourism Comfort Index (TCI) ([30]). This drives the current holiday market, next after cultural, social, landscape and other factors.

With growing incomes and increasing leisure time, the tourism industry in Europe is expected to continue to grow. However, temperature rise is likely to have some influence in summer (and other season) destination preferences in Europe, seasonality being a key issue in tourism. The effect of climate change might also make outdoor activities in northern Europe more attractive, while summer temperatures and heat waves in the Mediterranean, potentially exacerbated by water supply problems due to maximum demand coinciding with minimum resources availability, could lead to a redistribution or a seasonal shift in tourism away from the current summer peak.

Results from climate change models point towards a possible shift northward of tourism during the 21st century and an increasing bi-modal distribution of tourism over the seasons in the Mediterranean (i.e. either side of a significant dip in summer). At the same time northern European locations show increasing attractiveness for tourism. The PESETA maps indicate significant potential shifts in the climatic suitability for tourism, with the belt of excellent summer conditions moving from the Mediterranean towards northern Europe. The reduction in attractiveness of current summer resorts is likely to be at least partially offset by increased opportunities for tourism in northern Europe. In the shoulder seasons (spring and autumn, not shown here), TCI scores are generally projected to increase throughout Europe and particularly in southern Mediterranean countries, which could compensate for some losses experienced in summer.

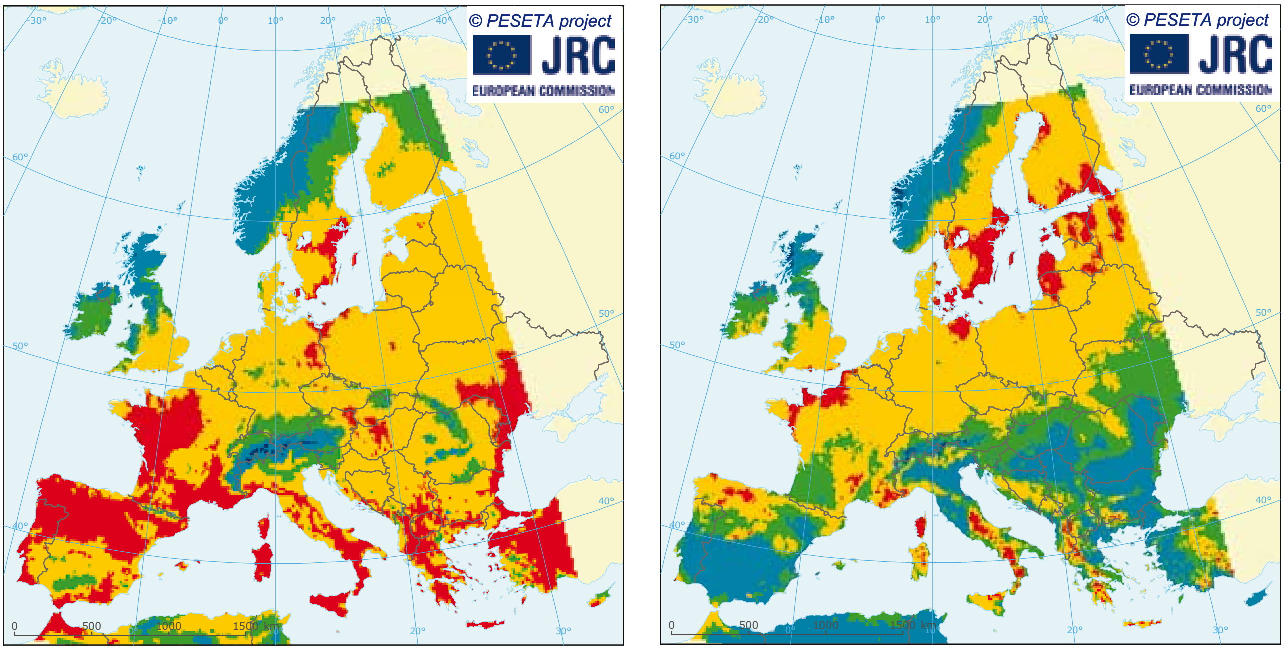
The above assessments reflect the theoretical (modelled) suitability of future tourism. Projections of the actual changes in tourism movements that are likely to occur, and their economic implications,

([30]) The Tourism Comfort Index is based upon a range of climate variables that reflects the suitability of regions related to an individual's bioclimatic comfort.

are much harder to assess. Much will depend on the flexibility of tourists and institutions such as schools (holidays). If summer remains the predominant season for tourism in Europe, major shifts of tourist flows may eventually occur. Shifts in the holiday season may however be the dominant form of adaptation. If these, as well as other societal changes (e.g. ageing population), allow for a more flexible timing of holidays among a large proportion of the population, some of these effects may be offset. Climate change may even be beneficial for the Mediterranean tourist industry if it levels-out demand, reducing the summer peak, while increasing occupancy in the shoulder seasons. In the absence of such adjustments, the Mediterranean tourist industry will be among the main losers. Some studies have investigated the potential economic effects of climate change on tourism and show an increase in the number of inbound tourists due to population and economic growth in the rest of the world; they also indicate that the influence of climate change may be rather to change the rate of relative growth in northern regions of Europe compared with the Mediterranean. The study also shows a potential shift towards a greater level of domestic tourism in regions with increasing attractiveness (e.g. within the United Kingdom).

There is also a major winter sports tourism industry in Europe, with the ski industry in the European Alps and Pyrenees attracting millions of tourists each year. This industry is a significant contributor to the economy (OECD, 2007), generating nearly EUR 50 billion in annual turnover. Studies project widespread reductions in snow-cover over the 21st century (IPCC, 2007b), which will affect the winter sports industry in Europe and its financial viability. Abegg *et al.* (2007) report that the numbers of snow-reliable ski areas in Austria, France, Germany, Italy, and Switzerland are projected to drop from approximately 600 to 500 if temperatures rise by 1.2 °C, to 400 if temperatures rise by 2 °C, and to 200 in a + 4 °C scenario.

Map 7.6 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: JRC PESETA project (http://peseta.jrc.ec.europa.eu/docs/Tourism.html).

There are already responses in place (e.g. artificial snow-making) and these have increased in recent years. For example, in France almost half a billion Euros were spent between 1990 and 2004 on artificial snow-making installations, while in Austria, approximately EUR 800 millions were spent between 1995 and 2003. The introduction of these machines is also driven by other socio-economic factors (increasing the reliability of resorts to increase revenues and expand their ski areas beyond previous natural limits). These measures have limits and their costs are likely to rise non-linearly as temperatures increases.

Adaptation options also pose sustainability and environmental problems (e.g. water use of snow-machines negatively affects current water resources, which could be exacerbated in the future, energy use and associated greenhouse gas emissions) that will need to be assessed. There is also a need to develop criteria for clearly defining and avoiding mal-adaptation. Finally, adaptation measures will have to be developed in synergy with mitigation actions. Sustainable adaptation measures exist, including economic diversification within or outside the tourism sector, e.g. from winter sports to other recreational or seasonal activities.

7.10 Health

Key messages

- Human beings are affected by climate change through direct or indirect exposures. These changes will have economic consequences. Few studies are available measuring the direct costs, such as treatment, hospitalisation, lost time at work, and additional medical costs.
- Health adaptation involves revising and strengthening a number of current measures, policies and strategies. Current levels of risk have already led to the introduction of new measures. As long as the increase in global warming is moderate, many of the projected effects on health are likely to be controllable by strengthening well-known public health interventions. Nevertheless, the cost-effectiveness of these actions will need to be further evaluated under a changing climate.
- Current actions, policies and measures might become insufficient at higher levels of risk or in the face of more frequent and intense events, or more rapid climate changes — which will have significant economic costs.

Globally, studies focused mainly on the welfare costs (and benefits) of climate-change impacts and aggregated the 'damage' costs of climate change (Tol, 2002a, 2002b) or estimate the costs and benefits of measures to reduce climate change (Cline, 2004). Those studies have shortcomings, such as: (a) a limited number of health outcomes is considered, mainly heat and malaria; (b) economists traditionally assign a lower value to life in lower income countries. Limited studies are available on the direct costs through e.g. work absenteeism, hospital admission, treatment costs, or work productivity.

In Europe PESETA estimated that the economic effects of climate change in Europe could be significant, with potentially large economic costs (billions of euro/year) from summer mortality by the 2080s, though these will be offset to a great extend by economic benefits from the reduction in winter mortality. Confalonieri *et al.* (2007) agree that projections of cold-related deaths, and the potential for decreasing their numbers due to warmer winters, can be overestimated unless they take into account the effects of better housing, influenza vaccination and season (Armstrong *et al.*, 2004). Alberini and Chiabai (2005*)* estimated that 286 million Euro can be saved in the city of Rome alone in 2020 if early action to prevent health illness is taken now.

Climate change also raises the issue of food safety. PESETA ([31]) estimated an extra 20 000 cases per year by 2030 and 25 to 40 000 extra cases by 2080, costing several billion euro a year in terms of medical expenses, lost time at work, expenses to avoid pain and suffering, and a small number of cases of fatal food poisoning. Adaptation is however found to offer a low-cost way to reduce these.

Coastal flooding is likely to threaten up to 1.6 million more people every year in the EU (EEA, 2007a). Direct health effects are caused by flood waters, and include drowning, heart attacks

Photo: © Waldemar Jarosinski

([31]) In PESETA only mean temperature-related mortality effects have been addressed, and not heat waves. For further details, see http://peseta.jrc.ec.europa.eu/docs/Humanhealth.html.

and injuries. Indirect health effects follow damage to infrastructure, and include infectious diseases, rodent-borne diseases, poisoning and post-traumatic stress disorder (sleeplessness, difficulties in concentration and psychosocial disturbances). The PESETA study estimated that coastal floods, in the absence of adaptation, could lead to economic costs of 0.8–1.4 billion euro by 2080 (B2 and A2 emissions scenario).

There is a number of emerging health issues from climate change in Europe, where quantification and valuation have not yet been explored. A warmer climate may have important effects on air quality in Europe (for ozone formation). The seasonality of allergic disorders may change with implications for direct costs in terms of over-the-counter medications for allergic rhinitis, and wider economic costs to individuals.

Data on adaptation costs, such as those related to surveillance and outbreak control, are starting to emerge, and adaptation strategies that can be implemented by health sectors (cCASHh project) are most likely to be built on well-established public health approaches, though further work is needed to fully assess the costs. Most adaptation measures appear to be low cost (e.g. provision of information), but large-scale vaccination or other prevention programmes against vector-borne disease are potentially very costly. They also highlight that there are likely to be strong distributional implications for climate change and health, with poorer countries being either more exposed or more vulnerable.

7.11 Costs of climate change for society

Key messages

- The total projected economic losses of the impacts of climate change are difficult to assess, and the literature shows a very wide range of results. Due to the many uncertainties involved, there is no one single 'true' cost but rather a range of costs that is relevant.
- Macro-economic and micro/sectoral economic assessments rely on different methodologies for different levels of analysis and purposes. They provide complementary estimates to better inform policy makers.

The costs of climate change will accrue to different individuals, in different sectors, in different places, and at different times. Due to this complexity, the total projected economic consequences of the impacts of climate change (globally or in Europe alone) cannot be easily assessed, and the literature shows a very wide range of results. The transposition of physical impacts into monetary terms is a difficult and sometimes contentious step, given that climate change impacts involve both market and non-market goods and services, covering health, environmental and social effects, and potential large-scale climatic events potentially irreversible in nature. The most common ways of defining the costs of inaction to climate change are either as 'total costs' or 'marginal costs'.

Total costs are usually measured as the discounted aggregate of all future welfare changes over some planning horizon. At the global level, there is an emerging literature, and studies have presented the total costs of climate change impacts to the world economy as a percentage change. For some regions, climate change could result in economic benefit for some of the sectors in the short to medium term. However, the evidence reported from the IPCC 4th Assessment Report is that the aggregated global impacts of climate change will result in net costs into the future and these costs will grow over time (IPCC, 2007b). On a global scale, previous economic estimates of the costs of climate change impacts — as a result of rising sea levels, falls in agricultural productivity and energy demand changes for instance — are up to around 2 % of global GDP per year (EEA, 2007b). But other studies and reviews have indicated that the costs may be more significant (Ackerman and Stanton, 2006). The Stern Review in particular (i.e. the British government's prominent report on the economics of climate change, 2006) takes a global perspective and estimates that if greenhouse gas emissions are not reduced, the total cost under a business-as-usual scenario will reduce welfare equivalent to a reduction in consumption per head of between 5 and 20 %.

The marginal costs of climate change are the additional damage costs of climate change from a current emission to the atmosphere of one unit of greenhouse gases. The IPCC (2007b) compiled the estimated marginal costs across some of the relevant studies in the literature and it can be seen how wide the range of results is. The estimates range from – 10 USD to + 350 USD per tonne of carbon. Peer-reviewed estimates have a mean value of USD 43 per tonne of carbon with a standard deviation of USD 83 per tonne (IPCC, 2007b). It is also important to note that the marginal cost of climate change is likely to increase over time, in line with the expected rising costs of damage (Watkiss, 2006).

While this information is very valuable in informing climate change policy, it is clear that there are many methodological issues involved in estimating the cost of inaction. Climate change is comprised of many types of climatic parameter, which in turn affect many sectors (market and non-market) in different ways. It is clear that different estimates of the costs of climate change are based on different types of climate effects, and include different impacts across different sectors. Literature reviews (Watkiss, 2006; EEA, 2007b) indicate that most studies focus on market damage from predictable events and leave out non-market and socially-contingent effects. All current estimates of the costs of inaction are therefore incomplete, though we do not know by how much. What is needed is recognition that the costs have a wide range and policies should be designed so that they take this uncertainty into account. Also, it should be clearly communicated that there is no one single 'true' cost out there which science could deliver to policy makers.