Assessment of the most significant threats to the EU posed by the changing climate in the short, medium and long term

"Climate Proofing" of key EU policies: report for task 1

In co-operation with

ALTERRA

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Executive Summary

Climate change can cause threats and opportunities for Europe. The main climatic drivers are temperature rise, changes in precipitation patterns, changes in intensity and frequency of extreme weather events (extreme precipitation, heat waves, cold spells, storms), sea level rise and changing wind patterns. These climatic drivers have an impact on the environment (water, soil, nature) and on society. They lead to impacts on the European environment and human society because they alter water systems, soils and biodiversity.

Impacts on water systems

With more drastic changes in climate towards the end of the 21st century, serious climate change impacts on water quantity and quality are expected in most European regions. Extreme precipitation events are likely happen more often and to become more intense. These may lead to high river flows, leading to flooding, loss of lives and economic damage (capital stock and infrastructure). The risks of flooding also increase due to population growth and cumulative economic investments, which leads to higher potential damages. Rising sea levels increase the risk of coastal floods, with a related risk of water pollution. Water availability tends to decrease in most European regions. The Mediterranean and eastern European regions will be the most vulnerable to water scarcity and drought due to climate change, while large parts of Europe might suffer from water stress due to an increase in water use. Throughout Europe the competition for water will increase.

Impacts on biodiversity

Biodiversity is already declining because of human expansion. Rising temperatures and changing precipitation patterns lead to northward moving of suitable climate zones for species, which puts biodiversity even more at risk. Environmental quality will change negatively as a result of climate change. A higher frequency of extreme events such as droughts and floods may lead to increased danger of extinction of local populations. Loss of ecosystems may lead to a loss of ecosystem services.

Impacts on soils

Although carbon storage in soils is related to changes in atmospheric CO_2 concentration, increased temperature and changing precipitation patterns, there is no strong evidence for an overall negative or positive impact on carbon storage. Climate change will increase erosion risks, especially in places where erosion is already severe. Landslides as a result of soil saturation with water from heavy rainfall and snow melt have mainly local effects in Europe, leading to loss of soil functions and increased vulnerability to erosion. Coastal erosion will also increase. Salinity of soils is expected to increase in coastal areas due to sea level rise.

Impacts on society and economy

Climate change increases the vulnerability of the European economy by threatening capital stocks,

infrastructure and specific impacts on several economic sectors. Extreme events are likely to occur more often and may become more severe, leading to increased damage risks.

Impacts on infrastructure

As a result of extreme events (floods, heat waves, forest fires, storms, etc) especially energy, traffic and communication networks have an increasing risk of damages and disruptions. Costs associated with monitoring and maintenance of these networks are likely to increase. Extreme events might also lead to transport restrictions. Flooded ports are not accessible and roads and railways can be blocked by floods and forest fires. The capacity of railways is limited by heat waves and traffic jams are more likely to occur during rainfall. Inland navigation will more often be faced with restrictions associated with extremely low and high river discharges. Changes in transport capacity may lead to changes in transport costs or to a shift between transport modalities. Economic impacts are closely related to the frequencies of damage-, disruption- and transport restriction events and the availability of transport alternatives.

Impacts on the energy sector

Energy production facilities that depend on the cooling function of rivers are doubly vulnerable: during a drought there is less water in rivers and their water temperature may be higher which restricts cooling water availability. For nuclear power plants a lack of cooling water may necessitate expensive shutdown events. Energy installations located in areas which are vulnerable to flooding should be built to withstand such effects. The prospect for renewables is affected by climate change in several ways. Low water flows affect hydropower. Biomass production will profit from higher temperatures in Northern Europe and will be limited in Southern Europe because of droughts. Human behaviour concerning energy use is altered by climate change. The demand for heating will go down and the demand for cooling goes up. In some places peak demand may shift from winter to summer.

Impacts on agriculture, forestry and fisheries

Climate change and climate variability affect agricultural production and farmers income. Effects of climate change on local economies in Europe may be substantial. Climate change and variability differs throughout Europe and for different farming systems. In general higher temperatures seem to be an advantage for crop yields in Northern Europe, whereas higher temperatures and persistent dry periods during summer will limit crop production in southern Europe. Weather extremes associated with damages such as droughts and extreme rainfalls are likely to occur more often. Climate change affects animal health, growth and reproduction. Increasing yield variability as a result of pests and diseases and severe storms is expected.

Impacts on forestry

Towards the end of the 21st century, severe and wide ranging negative climate change impacts on the forestry sector are expected in most European regions, with the Mediterranean region as the most vulnerable one to climate change. Forest fires are likely to dominate in southern Europe. The limited diversity of tree species in boreal forests enhances the risk of significant pest and disease impacts. Extreme storm events are likely to increase in north, west and central Europe, leading to economic losses.

Rising temperatures and CO_2 concentrations on the other hand increase forest productivity in northern Europe.

Impacts on fisheries

Fisheries will be influenced by climate change because it leads to an increase in the uncertainty about the state of the fish stocks. To the fisheries industry a loss of fish productivity may lead to lost revenues and increased distances to fishing grounds.

Impacts on industry

The industrial sector is generally thought to be less vulnerable to the impacts of climate change. Still the industrial sector can be affected by extreme weather events such as storms and floods which could lead to considerable damage to industrial facilities and infrastructure. Transport routes are affected which especially affects perishable commodities. Significant rises in insurance costs are expected, especially in relation to extreme events. The likely effects of climate change on the tourism sector vary widely, depending on the location and the season.

Impacts on human health

Due to higher temperatures heat related deaths and air pollution are expected to have a big impact on the health of the European population by 2020. The impact by 2080 is more uncertain. This problem might be more severe in cities. Problems with allergens are expected to increase, which may lead to high medical costs. Further development of the European health care sector is important to reduce the risk of vector borne diseases. Extreme events such as fires, droughts and floods will have direct and indirect health effects in the affected area.

Impact on urban areas

Urban areas combine economic activities, high population rates, dense infrastructure and large amounts of capital stock. Therefore, many of the previously mentioned impacts can have a combined effect on a city. Economic and social impacts are potentially high. The most serious impacts seem firstly urban heat and air quality deterioration that combined can lead to higher number of deaths during heat waves; and secondly extreme events like flooding and disruption of power systems through wind storm damage. In coastal areas cities are vulnerable to coastal flooding, coastal erosion and salt water intrusion due to sea level rise.

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1 Introduction and aim of the report

One of the four pillars of the EU adaptation framework is "integrating adaptation into EU key policy areas," which identifies the need for mainstreaming adaptation responses into all areas of EU policy that are impacted by climate change. The objective of mainstreaming is to ensure that the sectors covered by the policy areas are able to carry on with their core tasks even within the circumstances of a changing climate.

There are a number of completed or ongoing strategies and studies in the area of mainstreaming adaptation to climate change. This contract will build on those studies, filling the gaps, to provide an overview for mainstreaming climate adaptation in key EU policies where less effort has been spent so far.

Further, the streamlining of expenditures of EU funds under the next financial period and the mainstreaming of climate policy targets into these funds are crucial in order to ensure that these important financial instruments contribute to the overall EU objectives of adaptation.

The objectives of this study will be to:

- Assess the most significant threats and challenges posed by climate change to the EU.
- Identify the main challenges for EU policies to address these threats. The focus will be on those policies where currently no or little action has been taken.
- Identify the most appropriate measures that could be taken or adjusted to address these threats up until 2020 and to assess them against their economic impacts (where possible and useful, considering environmental and social effects as well[1]). The focus will be on measures in policy areas where currently no or little action has been taken on the EU level so far and which currently are not subject to ongoing assessments. The recommended measures should cover two aspects:
    - Targeted adaptation measures to be included in the next financial perspective of the EU.
    - How to make sure that measures funded under the next financial perspective of the EU are climate resilient (climate proofing).
- Assess how to climate-proof the funding of these key EU policy areas which will be identified on the basis of the analysis described above, in close coordination with the Commission.

This report assesses the most significant threats posed by the changing climate. It builds on the EU White paper on adaptation and adds the most recent findings from science.

[1] Social and environmental impacts might not be fully covered due to limitations in resources and time.

2 Methodology

"Vulnerability", a central concept in climate change research, has been defined in many different ways by various communities (Füssel 2007). Vulnerability to climate change in its general meaning is a measure of potential future impacts (a function of exposure and sensitivity) and a range of political, institutional, socio-economic and technical components (adaptive capacity) (IPCC 2007; EEA 2008, Hinkel 2011 in Schauser et al. 2011) (see Figure 2.1).

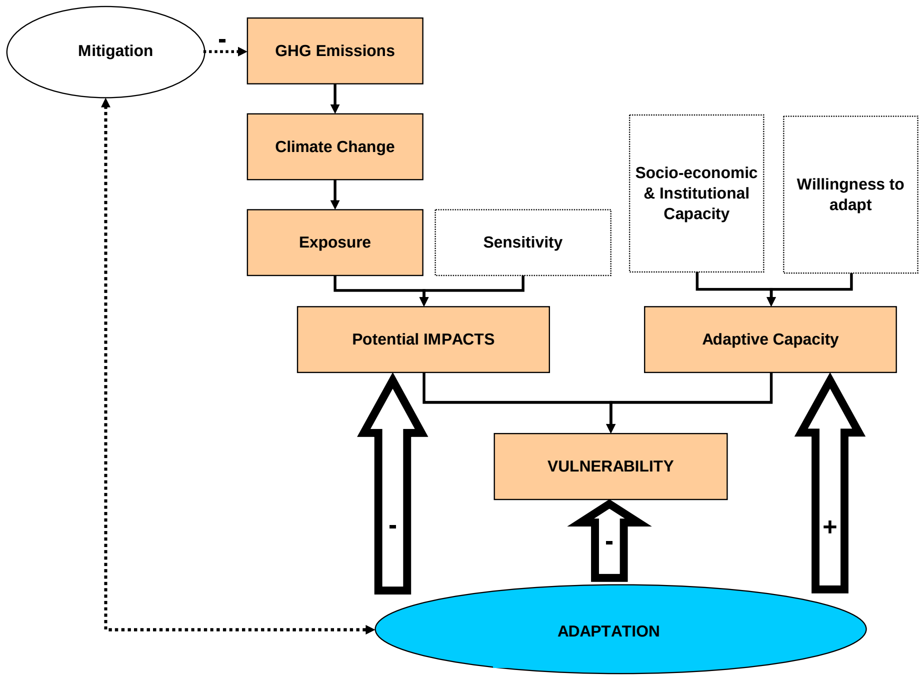

Figure 1: Conceptual diagram for climate change impacts, vulnerability and adaptation. Source: Isoard, Grothmann and Zebisch (2008) quoted in EEA (2008)

Although vulnerability assessments have been applied successfully in many cases and thus provide substantial support in the development of policies aiming at a reduction of future climate change impacts, a number of limitations have been identified. The most challenging constraint in the widely-used definition of vulnerability provided by the IPCC TAR 2007 (vulnerability as a function of exposure, sensitivity and adaptive capacity) focuses on the concept of adaptive capacity. In the IPCC TAR 2007, adaptive capacity is defined as "*the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences*". One of the main challenges posed by the very broad concept of adaptive capacity is that it requires a clear understanding of the addressed complex system (Keskitalo et al. 2010) with all its positive and negative feedbacks. Thus, adaptive capacity has proven to be difficult to translate into an action perspective and to be included in a model of vulnerability. Hence, selecting a few meaningful components for describing adaptive capacity (and the other functions of vulnerability) with regard to the overall purpose of the vulnerability estimate is recommended in the literature (Füssel 2010, Schauser et al. 2011).

In order to assess vulnerability in the context of this study the following indicators have been used (see also Figure 2.2). The indicators used to assess the impacts are:

- Climate scenarios
- Socio-economic scenarios
- Damage costs

and are further detailed in the Chapters three to six.

As indicators to evaluate adaptive capacity in the chosen policy areas we identified the following components:

- Estimated Adaptation Costs
- Current EU policy efforts
- National adaptation strategies (NAS) addressing sectoral adaptation
- EU Research activities

Further details can be found in Chapters eight to twelve.

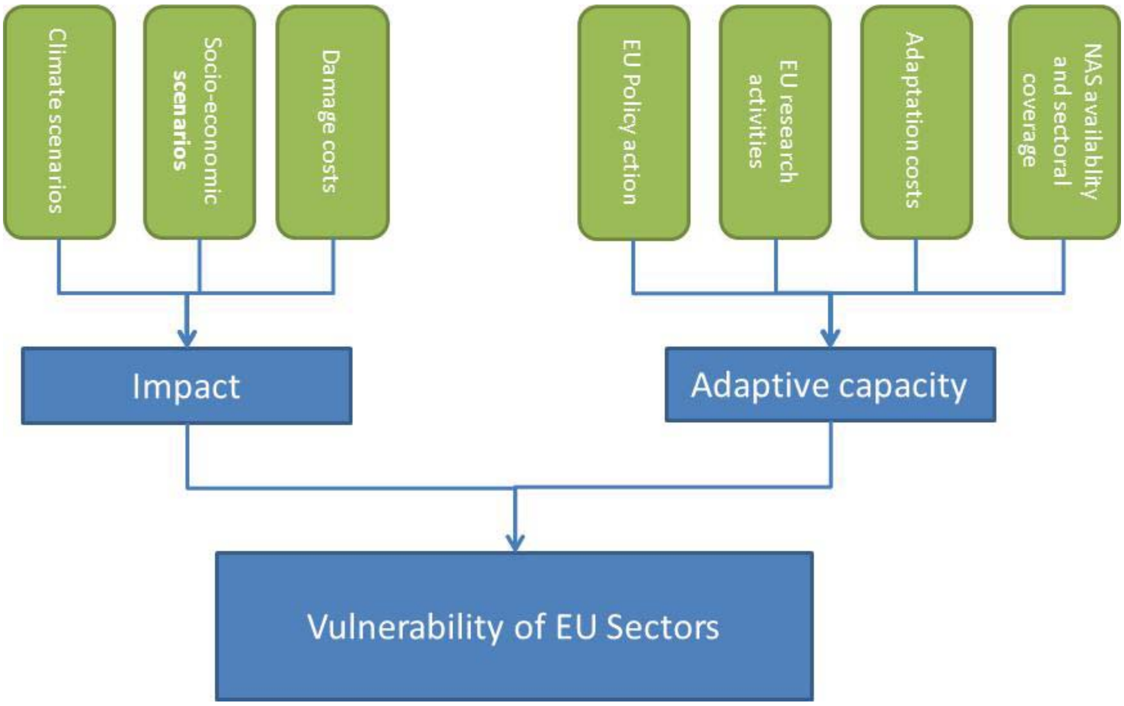

Figure 2: Indicators used to assess the vulnerability of EU sectors

The authors believe that these components will be useful to get a notion of the current adaptive capacity at EU level with full awareness that not all aspects of adaptive capacity of the EU are/can be covered. Nevertheless, taking these components into account to estimate vulnerability for each policy area seems meaningful and practical within the scope of this study. For example, the **estimates of adaptation costs** help policy makers in deciding upon various adaptation options and thus, may influence the political will to a certain degree. Further, the willingness to adapt is covered by **current EU policy efforts** as well as Member States´ **activities to set up a NAS**. Member States´ efforts in setting up a NAS also gives an indication on socio-economic and institutional capacity in terms of policy priorities and the national feasibility of getting involved in adaptation to climate change. The number of

Member States focusing on particular sectors in their NAS further shows the momentum of efforts in the EU.

Closely related to the willingness to adapt are issues of information and technology and thus, research on climate change and adaptation is of crucial importance. At the EU level, several **research programs** have financed projects on different climate change issues for a decade and thus, provide relevant information for policy making.

By consolidating the assessment of potential impacts, also considering damage costs, with data/information for the above described components of adaptive capacity chapter 10 provides a table proposing priority policy areas to be further screened. The proposal is founded on the findings of task 1 as well as expert judgement and shall be open for discussion with the COM on May, 4th 2011.

The results of this assessment are outlined in the following chapters. More detailed information on the methodologies applied can be found in each of the chapters below.

3 Scenarios for climate impact assessment in Europe

3.1 Introduction

In this chapter a summary is provided of published scenarios which are relevant for the evaluation of climate change impacts in Europe and the associated threats for EU policy sectors. Table 3.1 provides an overview of scenario exercises that are relevant in the context of evaluating climate threats to EU policies, distinguishing between scenarios for socioeconomic drivers, for climate drivers, and for climate impacts on the natural and socio-economic systems. The latter two categories will be further elaborated in task 1.2.

Socio-economic drivers can be important for three reasons. In the first place, factors like population and income growth and technological change lead to greenhouse gas emissions that determine the magnitude and rate of climate change and hence the potential impacts. Secondly, socio-economic developments can influence potential climate change impacts through changes in exposure and sensitivity. For example, increased production and use of bio fuels would influence the sensitivity of the energy system to climate change. Land-use changes, e.g. occupation of flood-prone areas, can increase exposure. Thirdly, socio-economic developments such as income growth, increased investments in health care, water efficiency or nature management would increase adaptive capacity. While the 1st factor is primarily relevant for the long term, the 2nd and 3rd issues also relate to the short and medium term. They not only determine vulnerability to climate change but also to current climate variability.

For analytical purposes it is established practice to work with a number of scenarios to capture the range of possible futures relevant for a specific objective or policy question. In other words, for different sectoral questions different scenarios are available that cannot be compared or combined directly, but can inspire an informed debate about specific future-related questions. Mainly for reasons of time and resource constraints, researchers often only use a limited selection of models and scenarios. E.g., the PESETA project (Ciscar et al., 2009, 2011) analyzed two out of the six IPCC scenarios (A2, B2) for two global circulation models (GCMs), while ESPON (2011, yet unpublished) limits the analysis to only one scenario and one GCM-RCM combination. In these studies, possible futures are only partly covered.

In Regions 2020 (EC 2008, 2009b), a climate change vulnerability index was developed to study the extent to which regions could be affected by the consequences of climate change, combining the physical and economic effects of the underlying processes. The index is based on change in population affected by river floods, population in coastal areas below 5m, potential drought hazard, vulnerability of agriculture, fisheries and tourism, taking into account temperature and precipitation changes.

Very recently, the Commission has published a reference scenario with current trends and policies and two variants in the strengths of policies, a low-end variation and a high-end variation of addressing greenhouse gas emissions. The three scenarios are to be used as a benchmark for future policy development "to deliver on the resource-efficient Europe flagship" (EC, 2011). These scenarios could also be used as a benchmark for the current project, addressing the questions: to what extent may climate change hinder the realization of the “high end variant” or even affect the relatively negative assumptions of the “low end variant”? See also Annex A.

Table 3.1: Scenario projects relevant for the evaluation of climate threats to EU policies

	Socio-economic drivers	*Climate drivers*	*Bio geophysical impacts*	*Economic impacts*
Global context	*IPCC SRES*		*IPCC AR4, MEA, UNEP-GEO*	*IPCC AR4*
Climate	*ADAM, ESPON*	*IPCC, PRUDENCE, ENSEMBLES, ESPON*		*CLIMATECOST*
Land-use change, soils	*EURURALIS (CLUE), SCENES,PLUREL*			
Water management: water safety, scarcity and droughts	*SCENES*		*SCENES, PESETA (LISFLOOD), ClimWatAdapt*	*PESETA (LISFLOOD)*
Biodiversity and ecosystems	*EURURALIS*		*EURURALIS, ATEAM*	
Agriculture	*Scenar, Prospects*		*PESETA, SEAMLESS*	*PESETA*
Forests	*UNECE/FAO Outlook*			
Fisheries and Aquaculture	*FAO Prospects, IFPRI*			
Energy	*DG TREN 2030 Trends, IEA Outlooks, Shell, Greenpeace, etc..*			
Infrastructure and buildings, including transport	*TRANSVIA*			
Industry and Services, including	*WTO Vision*		*PESETA*	*PESETA*

	Socio-economic drivers	*Climate drivers*	*Bio geophysical impacts*	*Economic impacts*
Tourism				
Health	*AGIR*		*CEHAPIS, PESETA*	*PESETA*
Coasts	*PESETA (DIVA)*	*IPCC*	*PESETA (DIVA)*	*PESETA (DIVA), PRC*
Urban areas	*MOLAND, PLUREL*		*PLUREL*	*PLUREL*

3.2 Global emissions scenarios

For the analysis of potential climate change impacts in Europe, usually the IPCC SRES[2] scenarios are still used for the global socio-economic context (Nakicenovic and Swart, 2000). Even if these scenarios were developed more than ten years ago and have been criticized[3], they can still be considered to capture the range of possible futures in terms of socio-economic development and associated greenhouse gas emissions, and hence they are still providing a relevant context for regional scenarios and a sound basis for long-term climate impact analysis. Their main input assumptions relate to development of population, income and technology, and their output includes energy demand and supply and greenhouse gas emissions. In 2010, the development of a new set of global scenarios started (Shared Socio-economic Pathways or SSPs) but results are not yet available. The SRES scenarios were used as the basis for new scenarios for other assessments (e.g., the Millennium Ecosystem Assessment, see Carpenter et al., 2005; and the UNEP-GEO, see UNEP, 2007) or country specific scenarios (e.g. national scenario exercises in Finland, The Netherlands, and the United Kingdom).

3.3 Global and European climate change scenarios

The SRES scenarios form the basis of most of the climate and climate change impacts scenario analyses available today, although also some climate change scenarios are still based on the previous IPCC scenarios (IS92) or theoretical constructs such as stable emissions or particular levels of long-term greenhouse gas concentration stabilization targets. An example of a scenario using a GHG target is the E1 scenario in the ENSEMBLES project, assuming stabilisation of atmospheric CO2 at 450 ppm equivalent by 2140.

[2] SRES: Special Report on Emissions Scenarios, see also http://www.grida.no/publications/other/ipcc_sr/?src=/climate/ipcc/emission/index.htm

[3] Initially they were suggested to be too high, and later to be too low, but recent analysis suggests that especially at the global level they still very well capture the range of possibilities, while the actual emissions fall within their range (van Vuuren and Riahi, 2008).

The ENSEMBLES project (FP6 2004-2009[4]) has delivered most of the climate modelling results that are used for analysis of climate change impacts in Europe. The ENSEMBLES objectives were:

- to develop an ensemble prediction system based on state-of-the-art, high resolution, global and regional Earth System models developed in Europe, validated against quality controlled, high resolution gridded datasets for Europe;
- to quantify and reduce uncertainty in the model representation of physical, chemical, biological and human-related feedbacks in the Earth System;
- and to maximise the exploitation of the results by linking the outputs of the ensemble prediction system to a range of applications.

Figure 4 shows the sequence of activities in ENSEMBLES. By comparing the results of the best available climate models, which each have their flaws, more could be learnt about the uncertainties and a broader range of futures could be explored. Figure 3 shows an example of such a combination of model results. ENSEMBLES builds on earlier projects like PRUDENCE (Prediction of Regional scenarios and Uncertainties for Defining EuropeaN Climate change risks and Effects [5], and the global and regional climate analyses are further developed, inter alia, in the context of IS-ENES (Infrastructure for the European Network for Earth System Modelling[6]) and CORDEX (COordinated Regional climate Downscaling EXperiment[7]), respectively.

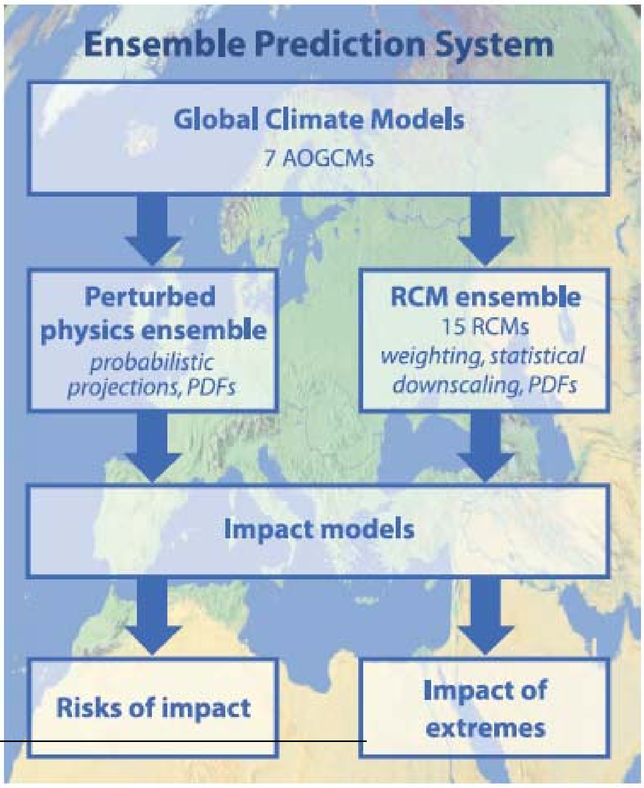

Figure 3: Linkages between the modeling components of the ensemble prediction system (EPS), as developed for use at multi-decadal to centennial timescales, and the methods of impact assessment using outputs from the system (van der Linden and Mitchell, 2009)

Figure 4 shows initial attempts to arrive at "probabilistic" [8] results for Europe, suggesting median estimates

[4] ENSEMBLES project: see http://ensembles-eu.metoffice.com/

[5] See http://prudence.dmi.dk/public/publications/PRUDENCE%20Final%20report.pdf

[6] See http://ec.europa.eu/research/infrastructures/pdf/is-enes.pdf

[7] See http://www.meteo.unican.es/en/projects/CORDEX

[8] Probabilistic: addressing multiple possible outcomes, by describing a range of outcomes with their level of uncertainty

of 7 degree temperature increases in central Europe, and precipitation decreases of 50% or more in selected areas of southern Europe in summer by the end of the century.

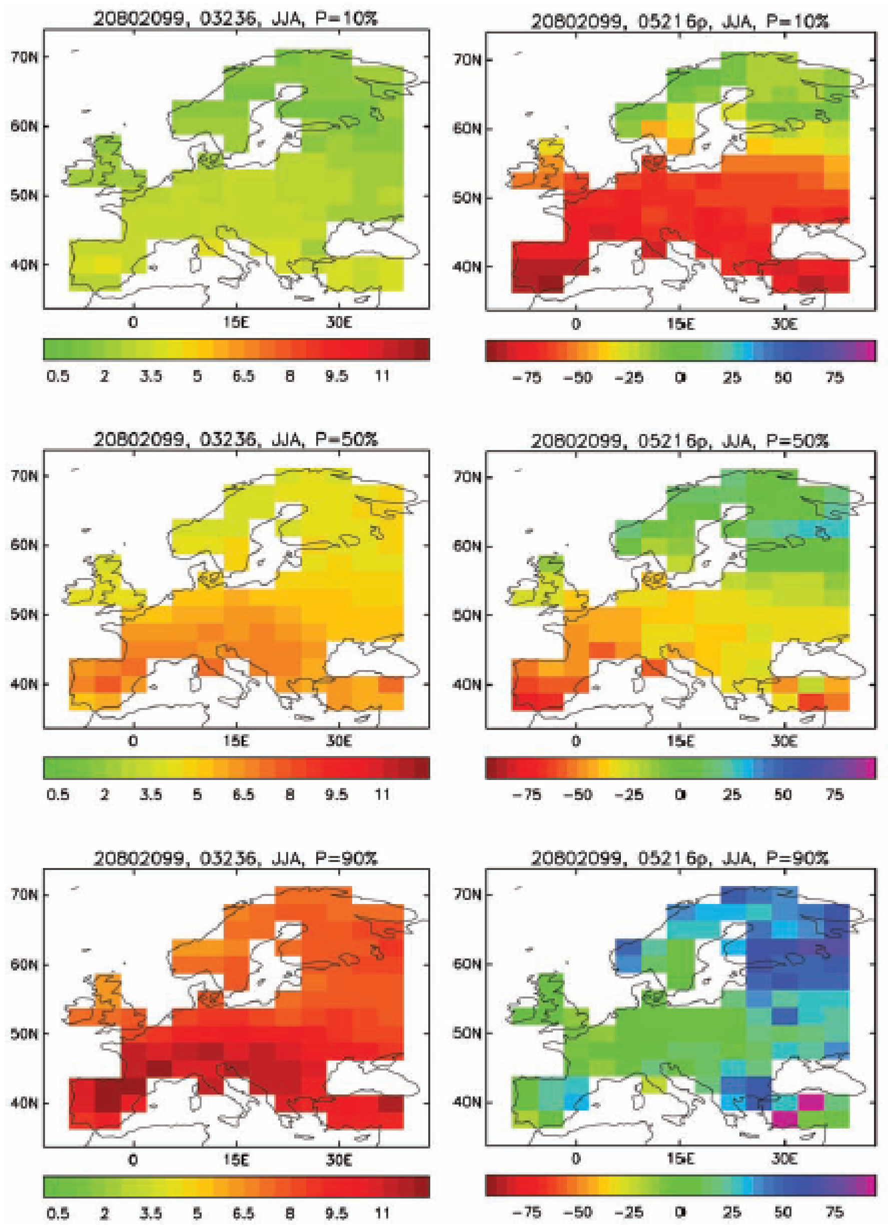

Figure 4: ENSEMBLES probabilistic projections for Europe under the A1B emission scenario produced by the perturbed physics parameter approach. The maps show the 10%, 50% (median) and 90% percentiles of European surface temperature change (left column) and European percentage precipitation change (right column), for the summer season for the period 2080-2099 relative to the 1961-1990 baseline period. Source: van der Linden and Mitchell (2009)

ENSEMBLES generated multi-model RCM projections for Europe at 25km resolution, on the basis of 7 GCMs and 15 RCMs (van der Linden and Mitchell, 2009). Because ensembles climate model experiments are complex and time consuming, not all SRES scenarios were analysed: the analysis of regional climate change using regional climate models focused on the A1B scenario.

Different RCM teams selected different GCMs to do their analysis. In this way, to some extent the uncertainties related to the selection of the boundary conditions (GCM) and the downscaling (RCMs) can be better captured. Because the climate change signal really starts to diverge for different emissions scenarios in the 2nd half of the century, the limitation to one emissions scenario is not necessarily a problem for analysis of climate threats for the coming decades.

The uncertainties are large, particularly with respect to precipitation. Figure 5 shows that not only the band width over the coming decades is very wide and includes both increases and decreases of precipitation, but also the effect of mitigation (reflected by the E1 scenario runs) does not lead to a significant departure from the "no-policy" range in the coming decades. The latter also applies to temperature, to a slightly lesser extent. Nevertheless, from the perspective of impact assessment it is important that the signal of the multi-model mean in the ENSEMBLES project is positive in all parts of Europe for near-surface temperature and is much larger than the standard deviation. Therefore the increase in temperature can therefore be interpreted as a robust signal (Goodess et al., 2009).

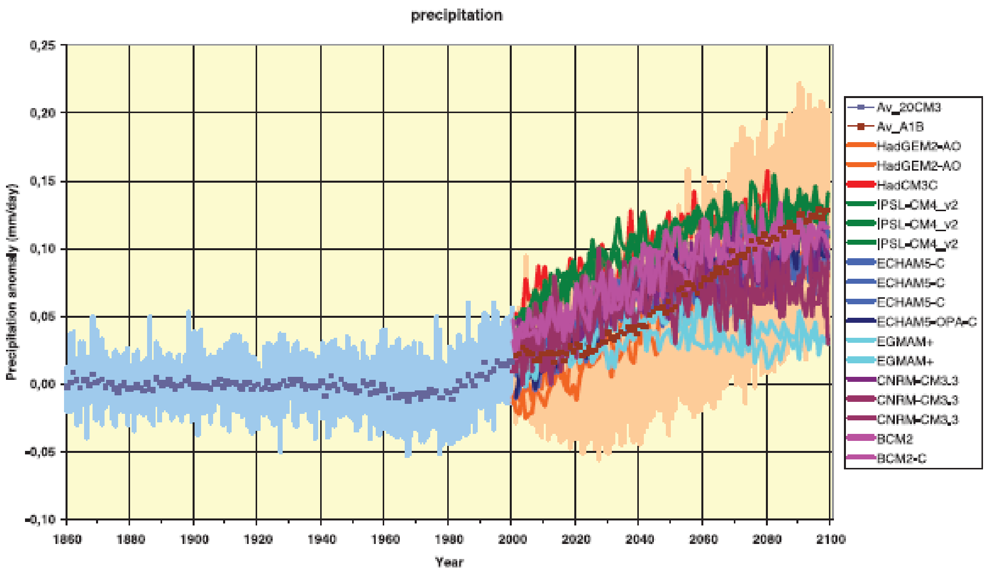

Figure 5: The global annual mean precipitation in 20C3M, A1B and E1 for the Stream 2 simulations (deviation from 1861–1890 mean). For 20C3M and A1B only, the average and range (minimum and maximum of all models for each year) of the simulations are displayed, and for E1 the individual model runs (source: van der Linden and Mitchell, 2009)

For precipitation, a pattern in Europe with two regimes, namely increased precipitation in the north and decreased precipitation in the south, can also be interpreted as a robust one. The number of models agreeing on an increasing precipitation signal reaches sixteen out of sixteen for the northern increase, and only two to four out of sixteen disagree with the decrease in the south (Goodess et al., 2009). More recent and yet unpublished regional climate modelling work in the context of the CLIMATECOST project suggests that uncertainties may be larger than estimated during ENSEMBLES. Another recent project in which additional regional climate model analysis was done with the objective to explore spatial climate impacts is ESPON-CLIMATE (2011), a project scheduling to publish its results in 2011, covering only one GCM-RCM combination and one scenario (A1B). Interestingly, ESPON (2011) dropped the initial idea to also analyze the SRES B1 scenario, suggesting that the likeliness of this relatively low emissions scenario would be low, even if it would not meet the formal EU 2 degrees target.

4 Damage and adaptation costs

4.1 Damage costs

In recent years, a number of studies have investigated the costs of adapting to climate change for Europe. Most of these studies have either adopted a sectoral focus, assessing the costs of adaptation for a particular sector, or have assessed the cost of adaptation in a specific EU country. Studies can be top-down – i.e. assessing the cost of adaptation from an economy-wide perspective based on economic models, or bottom-up – i.e. estimating the costs (and effects) of individual adaptation measures.

Comparison of the study results across countries and across sectors should only be done with the utmost caution since assumptions, definitions and methods differ greatly between studies. In some studies, adaptation is included to arrive at residual damage, in others it is not. The assessment of costs of potential climate impacts without adaptation, of "residual damage" after adaptation, and of adaptation measures (see 4.2) is in a very early stage. Assumptions can be different also as regards underlying climate scenarios, vulnerability assessments for sectors and regions, discount rates for future damage or the costs of adaptation measures, the assumed potential for autonomous adaptation, or the allocation of costs to climate change as one of many drivers of damage or adaptation measures. Other examples of differences between studies include different definitions of what establishes "costs" (e.g., valuation of market and non-market effects), spatial and temporal variation (distributional effects, discounting future damage/costs).

Most information is available for coastal impacts, with less results for water (floods), energy (primarily for changes in demand), health (cold and heat related deaths) and infrastructure (primarily for flooding), while for the other sectors only fragmented and anecdotal information is available. For some sectors, like soils, the impacts are very uncertain and we did not identify economic cost estimates for these impacts. The valuation problems apply above all to biodiversity, where different complications come together: first, the expected impacts of climate change are not sufficiently understood, neither is the potential for response measures. Second, both the effects of climate change and of possible adaptation measures are highly site-specific, depending on the characteristics of the ecosystem in question. And third, many of the costs and benefits of protecting biodiversity take the form of non-market values, and are therefore difficult to quantify in monetary terms.

Table 4.1 gives an overview of economic impacts of climate change for Europe as a whole and for different sectors, as it is available in the literature. In recent years, a number of studies have investigated the costs of climate change for Europe. Most of these studies have either adopted a sectoral focus, or have assessed the cost of damages in a specific EU country. Studies can be top-down – i.e. assessing the costs of damage from an economy-wide perspective based on economic models, or bottom-up – i.e. estimating the costs of damage in specific sectors. Several economic reviews are available on the impact of climate change. Stern (2006) states that if human society does not act, the overall costs and risks of climate change will be equivalent to losing at least 5% of global GDP each year, now and forever. If a wider range of risks and impacts is taken into account, the estimates of damage could rise to 20% of GDP or more. Aaheim et al. (2010) assessed the global impact of climate change for the E1 scenario. This scenario closely represent the achievement of the EU target to limit climate change. The conclusion of this report is that the impacts are modest, but unevenly distributed. Under an E1 scenario rich and fast growing regions are expected to gain, while the poorest regions bear the largest losses (Aaheim et al, 2010). For Europe, the PESETA project has calculated the impact of climate change for different sectors. It is one of the few projects that use a consistent set of scenarios and assumptions. The results have been aggregated to the European economy. According to Ciscar et al. (2009) the annual damage of climate change to the EU economy in terms of GDP loss is estimated to be between 20 billion € for the 2.5°C scenario and 65 billion € for the 5.4°C scenario with high sea level rise. The damages in GDP terms underestimate the actual losses (Ciscar et al, 2009). Currently, a follow-up to the PESETA project is incorporating new climate scenarios and an expanded set of sectoral analyses, but results are not yet available. The Conhaz project assessed the costs of natural hazards. This project will provide more insight into cost assessment methods, which is needed for integrated planning, budgeting and policy action prioritisation for the various natural hazards. In order to comprehensively capture this variability in cost assessment methods (source: http://conhaz.org/).

Table 4.2: Climate change damage costs overview table.					
sector	**Indicator**	**Geographical cover**	**Time frame or other indicator**	**Economic impact ***	**Literature**
Integrated economic impact	Changes in global GDP no and forever due to climate change	Global	From now on	- 5 % to – 20% GDP per year	Stern 2006
	Economic impact on European economy	Europe	2080	- 20 to – 65 billion €per year	PESETA, Ciscar et al, 2009
Soils and land use	NA**	NA	NA	Erosion due to sea level rise is included in coastal area part	NA
Agriculture	GDP losses and benefits	Northern Europe	2080	0.8%-1.1%GDP	PESETA, Ciscar et al, 2009
	GDP losses and benefits	Southern Europe	2080	-1.3 to -0.1%GDP	PESETA, Ciscar et al, 2009
	Changes of Gross Agricultural Product (GAP)	OECD – Europe	2.5 °C global temperature rise	0.55%GAP without adaptation 2.09% GAP with adaptation	Tol et al, 2002a
	Changes of Gross Agricultural Product (GAP)	Central and Eastern Europe and the former Soviet Union	2.5 °C global temperature rise	0.94%GAP without adaptation 2.65%GAP with adaptation	Tol et al, 2002a
	Changes inagricultural added value	Western Europe	2080 (A2 scenario)	- 6 to – 18 percent	Fisher et al. 2002

	Changes in agricultural added value	Former Soviet Union	2080 (A2 scenario)	0 - 23 percent	Fisher et al. 2002
	Changes in GDP	European Community	(GISS, GFDL UKMO, OSU scenario's)	- 0.3 to – 1.1	Darwin et al. 1999
Forestry	Impact of climate change on forestry	OECD – Europe	1 °C global temperature rise	134 million USD per year	Tol et al, 2002a
	Impact of climate change on forestry for a 1 °C global temperature rise	Central and Eastern Europe and the former Soviet Union	1 °C global temperature rise	-136 million USD per year	Tol et al, 2002a
Biodiversity	Impact of climate change on natural ecosystems	OECD – Europe	1 °C global temperature rise	- 14.7 million USD per year	Tol et al, 2002a
	Impact of climate change on natural ecosystems	Central and Eastern Europe and the former Soviet Union	1 °C global temperature rise	- 5.4 million USD per year	Tol et al, 2002a
Fisheries	Damage due to decline Gross revenues	World	NA	decline in current gross revenues of up to 50% (about $80 billion per year) from the world's fisheries caused by severe climate change and overfishing	World bank, 2010
Water	Expected additional economic damage due to river floods	Northern Europe	2080	- 0.3 – 0 billion € per year	PESETA, Ciscar et al, 2009

	Expected additional economic damage due to river floods	British Islands	2080	0.8 – 5.0 billion € per year	PESETA, Ciscar et al, 2009
	Expected additional economic damage due to river floods	Central Europe North	2080	1.5 – 5.3 billion € per year	PESETA, Ciscar et al, 2009
	Expected additional economic damage due to river floods	Central Europe South	2080	2.9 – 5.0 billion € per year	PESETA, Ciscar et al, 2009
	Expected additional economic damage due to river floods	Southern Europe	2080	-0.1 to – 2.3 billion € per year	PESETA, Ciscar et al, 2009
	Expected additional economic damage due to river floods	Europe	2080	7.7 – 15.0 billion € per year	PESETA, Ciscar et al, 2009
	Expected additional economic damages as a result of floods in river systems under A1B scenario	Europe	2020s	20.4 billion € per year climate and socio-economic change; 9.0 B€/yr. marginal climate change impact (undiscounted)	Feyen and Watkiss (2011) (ClimateCost)
	Expected additional economic damages as a result of floods in river systems under E1 scenario	Europe	2020s	14.6 billion € per year climate and socio-economic change; 5.4 B€/yr. marginal climate change impact (undiscounted, no adaptation)	Feyen and Watkiss (2011) (ClimateCost)
	Expected additional economic damages as a result of floods in river systems under A1B scenario	Europe	2050s	45.9 billion € per year climate and socio-economic change; 18.9 B€/yr. marginal climate change impact (undiscounted, no adaptation)	Feyen and Watkiss (2011) (ClimateCost)

	Expected additional economic damages as a result of floods in river systems under E1 scenario	Europe	2050s	41.7 billion € per year climate and socio-economic change; 20.3 B€/yr. marginal climate change impact (undiscounted, no adaptation)	Feyen and Watkiss (2011) (ClimateCost)
	Expected additional economic damages as a result of floods in river systems under A1B scenario	Europe	2080s	97.9 billion € per year climate and socio-economic change; 15.3 B€/yr. climate only (undiscounted, no adaptation)	Feyen and Watkiss (2011) (ClimateCost)
	Expected additional economic damages as a result of floods in river systems under E1 scenario	Europe	2080s	68.2 billion € per year climate and socio-economic change; 30.6 B€/yr. marginal climate change impact (undiscounted, no adaptation)	Feyen and Watkiss (2011) (ClimateCost)
	Economic impact (agriculture and energy) of the drought in the Ebro river basin (Spain)	Ebro river basin (Spain)	2005	Direct loss of gross added value: € 482 million Indirect loss of production: € 377 million.	Perez y Perez et al. 2009
Energy	Investment costs (cooling systems) and additional electric generation costs due to cooling	Europe	2050	Investment 8.4 billion € Generation 7.3 billion € per year	ADAM, Jochem et al, 2009
	Additional energy saving due to 4 % °C temperature rise in 2050	EU27+ Norway and Switzerland	2050	- 27.5 billion € per year	ADAM, Jochem et al, 2009
	Additional spending for electricity generation on annual basis	Greece	2080	170-770 million € per year	Mirasgedis et al, 2007

	Associated costs for energy demand (electricity) as a result of temperature rise as a percentage of GDP	Finland Germany Spain	2020	- 0.35%GDP - 0.07%GDP (coal) - 0.05%GDP (oil and gas) 0.22%GDP 0.16%GDP (gas)	Pilli-Sihvola, 2010
	Potential and average changes in income	Large nuclear plant in central Europe	increase of river temperature (1 – 5°C) and a decrease of stream flow (10%-50%)	Average - 80 million € per year Potential - 110 million € per year	Föster and Lilliestam, 2009
	Increase in heating energy consumption	OECD - Europe	1 °C global temperature rise	- 13.1 billion USD per year	Tol 2002, after Downing, 1995, 1996
	Increase in heating energy consumption	Central and Eastern Europe and the former Soviet Union	1 °C global temperature rise	- 46.0 billion USD per year	Tol 2002, after Downing, 1995, 1996
	Increase in cooling energy consumption	OECD – Europe	1 °C global temperature rise	20.2 billion USD per year	Tol 2002, after Downing 1995, 1996
	Increase in cooling energy consumption	Central and Eastern Europe and the former Soviet Union	1 °C global temperature rise	18.6 billion USD per year	Tol 2002, after Downing 1995, 1996

	Overall costs of climate change on electricity sector in Europe	EU27	2080	49 billion € per year of which 13 billion is related to the grid and the rest to production	Rademaekers et al 2011
Transport and infrastructure	Costs of weather events for the transport system (transport mode and infrastructure)	EU	Current	Road: €1.8 B/year Rail: €0.3 B/year Air: € 0.4 B/year	Enei et al. 2011 Weather project
Industry and tourism	Changes in tourism expenditures receipts at annual basis	Northern Europe	2080	0.3 – 2.4 billion € per year	PESETA, Ciscar et al, 2009
	Changes in tourism expenditures receipts at annual basis	British Islands	2080	0.5 – 3.4 billion € per year	PESETA, Ciscar et al, 2009
	Changes in tourism expenditures receipts at annual basis	Central Europe North	2080	0.4 – 2.3 billion € per year	PESETA, Ciscar et al, 2009
	Changes in tourism expenditures receipts at annual basis	Central Europe South	2080	0.6 – 5.0 billion € per year	PESETA, Ciscar et al, 2009
	Changes in tourism expenditures receipts at annual basis	Southern Europe	2080	- 1.7 to – 12.8 billion € per year	PESETA, Ciscar et al, 2009
	Changes in tourism expenditures receipts at annual basis	Europe	2080	0	PESETA, Ciscar et al, 2009
Health	Heat waves, damages related to additional deaths with acclimatisation	Europe	2020	2 – 4 billion € per year	PESETA, Ciscar et al, 2009

	Heat waves, damages related to additional deaths with acclimatisation	Europe	2080	8 - 80 billion € per year	PESETA, Ciscar et al, 2009
	Heat waves, damages related to additional deaths without acclimatisation	Europe	2020	13 – 30 billion € per year	PESETA, Ciscar et al, 2009
	Heat waves, damages related to additional deaths without acclimatisation	Europe	2100	50 - 180 billion € per year	PESETA, Ciscar et al, 2009
	Cold spells, benefits from avoided deaths without acclimatisation	Europe	2020	23 – 110 billion per year	PESETA, Ciscar et al, 2009
Coastal areas	Losses to flooding	Europe	2020	6.0 billion € per year (without adaptation) 1.1 billion € per year (with adaptation) Adaptation costs 1.0 billion € per year	PESETA, Ciscar et al, 2009
	Losses to flooding	Europe	2080	18.2 billion € per year (without adaptation) 1.2 billion € per year (with adaptation) Adaptation costs 1.0 billion € per year	PESETA, Ciscar et al, 2009
	Losses to salt intrusion	Europe	2020	0.6 billion € per year	PESETA, Ciscar et al, 2009

	Losses to salt intrusion	Europe	2080	1.1 billion € per year	PESETA, Ciscar et al, 2009
	Migration costs		2020	0.3 million € per year (without adaptation) 0.2 million € per year (with adaptation) Adaptation costs 1.0 billion € per year	PESETA, Ciscar et al, 2009
	Migration cost	Europe	2080	25.2 billion € per year (without adaptation) 20 billion € per year (with adaptation) Adaptation costs 1.0 billion € per year	PESETA, Ciscar et al, 2009
	Annual costs (salinization, moving and land loss) for Europe under A1B scenario	Europe	2020	5.2 (5.0-5.6) billion per year; Socio-economic and climate change together, no discounting, no adaptation 2.4 (2.2-2.7) B€/yr. marginal effects climate change signal only	Brown et al. 2011 (Climatecost)
	Annual costs (salinization, moving and land loss) for Europe under E1 (2^{o}C) scenario	Europe	2020	5.6 (5.2-5.8) billion per year; Socio-economic and climate change together, no discounting, no adaptation 2.8 (2.3-2.9) B€/yr. marginal effects climate change signal only	Brown et al. 2011 (Climatecost)

	Annual costs (salinization, moving and land loss) for Europe under A1B scenario	Europe	2050	10.6 (9.9-11.7) billion € per year Socio-economic and climate change together, no discounting, no adaptation 6.2 (5.5-7.3) B€/yr. marginal effects climate change signal only	Brown et al. 2011 (Climatecost)
	Annual costs (salinization, moving and land loss) for Europe under E1 (2°C) scenario	Europe	2050	11.7 (11.1-12.5) billion € per year Socio-economic and climate change together, no discounting, no adaptation 6.7 (6.0-7.5) B€/yr. marginal effects climate change signal only	Brown et al. 2011 (Climatecost)
	Annual costs (salinization, moving and land loss) for Europe under A1B scenario	Europe	2080	25.4 (19.3-37.2) billion € per year Socio-economic and climate change together, no discounting, no adaptation 18.4 (12.4-30.2) B€/yr. marginal effects climate change signal only	Brown et al. 2011 (Climatecost)
	Annual costs (salinization, moving and land loss) under E1 (2 °C temperature rise)	Europe	2080	17.4 (15.8-20.1) billion € per year; Socio-economic and climate change together, no discounting, no adaptation 10.4 (8.9-13.1) B€/yr. marginal effects climate change signal only	Brown et al. 2011 (Climatecost)
	Monetary damage caused by flooding, salt intrusion, land erosion and migration,	Europe	2100	17 billion USD/year	Hinkel et al. 2010

	Impact of sea level rise	OECD – Europe	1 meter sea level rise	1.7 billion USD per year	Tol et al, 2002a
	Impact of sea level rise	Central and Eastern Europe and the former Soviet Union	1 meter sea level rise	0.5 billion USD per year	Tol et al, 2002a
Urban areas	NA	NA	NA	Economic impacts are described in above sections. Especially river floods, coastal areas, health and energy are relevant for cities. However damages are not yet calculated for individual cities	NA

* Units: %GDP = percentage of Gross Domestic Product; GAP = Gross Agricultural Product, € = Euro, USD = United States Dollars.
** NA = Not Available

4.2 Adaptation costs

At global scale different studies are available on the costs of climate adaptation (UNFCCC (2007), Stern, 2007). The UNFCCC report concluded that total adaptation costs by 2030 could amount to $49 – 171 billion per annum globally. According to the UNFCCC the adaptation costs in developed countries are estimated at USD 7 Billion/year for agriculture, 2 B$/y for water, 7B$/y for coastal zones and 6-88B$/y for infrastructure. According to Perry et al, (2009) the UNFCCC are likely to be substantial underestimated. The OECD also estimated adaptation cost curves with two integrated assessment models. (DICE and RICE). Both models are not able to capture adaptation satisfactorily. Many models do not specify the damages from climate change, and those that do mostly assume implicitly that adaptation is set at an "optimal" level that minimizes the sum total of the costs of adaptation and the residual climate damages that might occur (de Bruin et al. (2009). The results show that at the end of the 21st century in the case of prolonged inaction, damages may have risen to more than 5 trillion dollars annually. A third of those damages can be avoided by spending some 250 and 370 billion dollars annually on adaptation and mitigation respectively (de Bruin et al. (2009). Agrawala et al. (2010) performed a global study on the impact of climate change and the costs and benefits of adaptation. This OECD study also used the DICE, RICE model and the WITCH model. The study shows that initial levels of adaptation can be achieved at very low normalized costs. Thereafter, investments in adaptation show decreasing marginal benefits (Agrawala et al. 2011). The estimated costs depend critically on the climate damage function. These functions are based on limited sectoral and geographical information cover. Also the choice of model introduces uncertainty. In this study only two models are used. The global damages of a 2.5 °C temperature rise are estimated at 1.5 % of the GDP. The adaptation costs for Western Europe are estimated at 0.0 to 0.12 % GDP in 2050 and 0.4 to 0.8 % GDP by 2100 (Agrawala et al. 2011). The model outcomes show that building capital stock and adaptive capacity become effective with a time delay and should be implemented early (Agrawala et al, 2011). The adaptation costs for different sectors in Europe by a 2.5 °C temperature rise are estimated. For agriculture the adaptation costs are estimated at 0.1 % of the GDP, for coastal zones at 0.31 % of the GDP, for health at 0.01 % of the GDP at 0.18 % of the GDP. The study takes into account that adaptation leaves a residual damage (Agrawala et al. 2011).

The attention to the economics of climate change impacts and adaptation in Europe is relatively new. Both research and policy have focused on the climate system, potential physical and ecological climate impacts and on mitigation up to very recently. The first national adaptation strategy was agreed in Finland only in 2005 and none of the National Adaptation Strategies in Europe developed since that time consider economic costs of damage and adaptation in a quantitative fashion (Swart et al., 2009). Many projects[9] are on-going and do not have results yet, or the deliverables are under review (e.g. Climatecost reports) and not yet publicly available. Checking the possibly relevant information in these projects is beyond the scope of the current project. The kind of cost estimates available and presented in this report may give a general idea of the order of magnitude of damage and adaptation costs under certain assumptions, but they may not be very relevant for the

[9] Footnote: A large number of FP7, Interreg and national projects may address costs of damage and adaptation but are on-going and did not yet publish quantified economic estimates (see Annex, list courtesy Paul Watkiss):

assessment of sectoral climate resilience. For that purpose, a more relevant approach would be to undertake an Investment and Financial Flow analysis, i.e. to assess current programmes, funding and investment and then assess what actions and marginal costs are needed to make these existing policies resilient (Paul Watkiss, personal communication).

In the report, adaptation costs are related to sectors and themes, although it is actually not the theme which causes adaptation costs, but the respective adaptation measure. While there are many potential adaptation measures feasible an each sector and theme, the analysis is limited to the most typical and mostly mentioned adaptation measures. Many literature sources indicate only adaptation costs per sector without explicitly describing the measures, which justifies this approach.

In this study we use an aggregated class for adaptation costs. In the table under the column "Adaptation costs" three classes are used: Low, Medium and High. This classification bases upon a comparison of estimated adaptation costs between sectors. E.g., adaptation to productivity changes in agriculture is relatively inexpensive in comparison to the other sectors and themes, whereas adaptation measures in response to those themes related to "high adaptation costs" belong to the most costly measures. The category "high" represents roughly the upper third part of sectors with the highest adaptation costs, and so on.

The column "Sources" comprises only studies which give information for Europe, not for smaller regions, countries or localities. This literature (and additional bottom-up-literature) will be reviewed in Task 2.2. In the column "Notes" additional information is given to highlight certain aspects of the adaptation costs assessment in the sector, if necessary.

Note that this qualitative approach has been chosen in order to achieve comparability across the sectors. Quantitative estimates are partly available, but less comparable due to different methodologies, regional coverage, adaptation definitions and study objectives. Much of what is said in 4.1 on the comparability of climate damage estimates also applies to adaptation costs. In addition, usually only a limited amount of damage types (e.g., direct damage) or adaptation measures (e.g., "hard" "grey" measures, like dikes, that can be valued more easily than "green" measures like measures building with nature or greening cities, and "soft" measures, like institutional changes or emergency planning) are included in adaptation cost estimates. This may distort comparisons between adaptation costing studies, and makes usage of the numbers for prioritizing between sectors dangerous.

Table 4.2 exhibits the estimates available in the literature for adaptation costs. The Climate cost project has reviewed the costs and benefits of adaptation for a number of sectors using a consistent methodology, but most deliverables are under review and have not yet been published (http://www.climatecost.cc/). The review covers European, sectoral, national and regional studies. The key findings of this review are that the knowledge on adaptation cost estimates is limited and is unevenly distributed across policy sectors and European countries. In many of the EU countries adaptation strategies have been developed, but they have not yet been translated into concrete policies or projects, and hence there is no evidence base on which cost assessments can build other than model calculations. Often, measures were initially or primarily taken for reasons other than climate change. For example, greening of cities and flood risk measures are (partly) relabelled as adaptation, without specification of the additional costs for adaptation. The largest number and most sophisticated studies exist for the coastal area. For other sectors the coverage is more limited. There are several studies on the cost and benefits of energy demand adaptation, and some estimates for the health sector. For agriculture there are studies of autonomous adaptation, but relatively few that include planned adaptation. There are also a few studies on water resources and tourism. The most detailed information at the national scale is available for the Netherlands, Sweden and the UK. The assessments vary in methodological approaches, metrics, time periods and assumptions. Therefore they are difficult to compare.

The table summarises only studies that give information at the European level; not for smaller regions, countries or localities. This literature (and additional bottom-up-literature) will be reviewed in Task 2.2. The table is divided into two parts. The left side of the table focuses on quantitative cost estimates, mainly from the integrated assessment model literature. These estimates are generally not comparable between sectors, studies and time frames due to differences in methodologies, regional coverage, adaptation definitions and study objectives. Moreover, only parts of the sectors and relevant themes are covered. That is why we add the second part on the right side of the table, presenting qualitative cost estimates. We use three classes to describe the adaptation costs; high, medium and low. This classification is based on a comparison of estimated adaptation costs between sectors. For example, adaptation to the climate impacts on productivity in agriculture is relatively inexpensive in comparison to the other sectors and themes. The category “high” represents roughly the upper third part of sectors with the highest adaptation costs. In the column “Notes” additional information is given to highlight certain aspects of the adaptation costs assessment in the sector.

Table 4.2: Climate change adaptation costs overview table.

Sector	Response to Theme	Quantitative cost estimates			Qualitative cost estimates		
		Estimates*	**Regional coverage and time frame**	**Sources**	**Estimates**	**Notes**	**Sources**
Soils and land use	Economic damages as a result of soil degradation and erosion				Soils: Low Land use: High (indirect)	Soils: Low coverage, existence of adaptation measures questionable Land use: High costs for the inhabitants in case of resettlement	
Agriculture	Productivity	0.1% of GDP	total Europe, +2.5°C	Agrawala et al. 2010	Low (2.5°C scenario)	Main measures: crop change and change in seeding/harvesting dates. Low coverage, but literature suggests benefits are higher than costs for most measures	Agrawala et al 2010
	Damage due to floods				Medium (2030, 2060s)	See sector Water, but no estimates specific to flood adaptation in agriculture available	
	Damage due to water scarcity Damage due to droughts	6 to 22 million USD per year for agricultural water supply	2030, OECD Europe	UNFCCC 2007	Medium (2030, 2060s, up to 2080)	See sector Water. Low coverage, but literature suggests benefits are higher than costs for most measures. More estimates are given for developing countries, incl. Eastern Europe	Fischer et al 2007, Bosello et al 2009, Agrawala et al 2010
		7.8 billion USD per year	2060s, Western Europe	Bosello et al. 2009			

Sector	Response to Theme	Quantitative cost estimates			Qualitative cost estimates		
	Damage due to diseases and pests				High (no indication of time frame)	Possibly costly measures available (R+D, chemical protection), but low coverage for adaptation cost	
	Damages to temperature rise, water shortage	0.1 % of GDP (EU) with a 0.39 % residue damage of GDP EU	Europe	Agrawala et al. 2011			
Forestry	Productivity				Low (no indication of time frame)	Main measures: change in planted trees and change in seeding/harvesting dates. Literature suggests benefits are higher than costs for most measures	
	Damage due to fires				Medium (no indication of time frame)	Main measures: Technical Monitoring systems and forest aisles	EFI et al 2008
	Damage due to pests				High (no indication of time frame)	Possibly costly measures available (R+D, chemical protection), but low coverage for adaptation cost	EFI et al 2008
	Damage due to storms				Medium (no indication of time	Main measures: forest aisles, change in planted trees	EFI et al 2008

Sector	Response to Theme	Quantitative cost estimates			Qualitative cost estimates		
					frame)		
Biodiversity	Shifting habitat zones				Medium to High (2030)	Low coverage, estimates are more of a "educated guess" (UNFCCC 2007) Estimates are higher than for health, coastal zones, Severe distinction problems from non-adaptation costs	UNFCCC 2007 Parry et al 2009
Fisheries	Fish stocks	0,27 to 1,12 billion USD per year (direct costs in mild scenario).	Europe; increases over time from the short term (2010-19), peak in the mid-term (2020-49)	World Bank 2010, EPOCA	Medium to High	The loss in gross revenues, household income, and the endowment required to offset the losses under all climate change scenarios and with a 5 percent discount rate. High uncertainties with cost estimation.	World Bank 2010, EPOCA
	Acidification				Medium to high	No estimates for Europe available yet. The only study available is from the US. This study of US commercial fishery revenues concerning adaptation costs caused by acidification is focusing on molluscs. It forecasts substantial revenue declines, job losses, and indirect economic costs.	Cooley, S. & Doney, S. 2009, EPOCA, BIOACID
Water	Floods		Europe (E1-A1B)	Feyen and Watkiss (2011) (ClimateCo	High (2030, 2060s, 2080s)	One of few sectors with estimates following economic cost-benefit calculus, but still with a wide uncertainty range partly due to	Bosello et al 2009, PESETA, UNFCCC
		0.8-1.1 B€/yr	2020 Climate				

Sector	Response to Theme	Quantitative cost estimates			Qualitative cost estimates		
			change only	st)		uncertain sea level rise	2007, Agrawala et al 2010
		1.2-1.7 B€/yr	2020 Climate change and socio-economic changes				
		1.1-1.4 B€/yr	2050 Climate change only				
		3.2-3.4 B€/yr	2050 Climate change and socio-economic changes				
		1.1-2.4 B€/yr	2080 Climate change only				
		4.7-7.9 B€/yr	2080 Climate change and socio-economic changes				
	Water resources/water scarcity				Medium (2030, 2060s, up to 2080)		Fischer et al 2007, Bosello et al 2009, UNFCCC 2007, Agrawala et al 2010
	Droughts						

Sector	Response to Theme	Quantitative cost estimates			Qualitative cost estimates		
	Water quality				Uncertain	Very low coverage	
Energy	Renewable energy				Medium (no indication of time frame)	Change of location of renewable power plants, costs not assessed in literature Costs will be diverse for different types of renewable energy	
	Thermal facilities	1 billion per year for alternative cooling of thermal power generation	2050, EU27 plus Norway and Switzerland	Jochem and Schade 2009 (ADAM)	High (up to 2060s)		Jochem and Schade 2009, Bosello et al 2009
	Offshore and coastal production				Low (no indication of time frame)	According to expert statements (personal communication), structures are sufficiently weather-proof to withstand climate impacts	
	Energy distribution infrastructure	14.8 to 18.4 billion € per year including climate impacts	2080, EU27	Rademaekers et al. 2011	High (2010-2050, 2060s)	Climate proofing of infrastructure	World Bank 2009, Bosello et al 2009
	Energy security				High (up to 2060s)	See "Thermal facilities"	

Sector	Response to Theme	Quantitative cost estimates			Qualitative cost estimates		
	Energy demand	-8.8 billion USD per year due to less heating expenditure	2060s, Western Europe	Bosello et al. 2009	Low or Negative	In some cases negative costs, in other words, a net benefit is expected. High regional heterogeneity	Bosello et al. 2009, Jochem and Schade 2009 (ADAM)
		-7 to -27.6 billion € per year due to less heating expenditure	up to 2050, EU27 plus Norway and Switzerland	Jochem and Schade 2009 (ADAM)			
		4.3 to 8.4 billion € per year for additional cooling devices	up to 2050, EU27 plus Norway and Switzerland	Jochem and Schade 2009 (ADAM)			
Infrastructure and transport	Road				High (up to 2050)	"Educated guess" without empirical backing, low coverage of quantitative cost assessments, but existing studies indicate high costs	Jochem and Schade 2009
	Rail						
	Aviation				Low (no indication of time frame)	Few adaptation measures available – sector is already well equipped with weather-monitoring systems	
	Shipping				Medium (no	Main costs arise in connection to	

Sector	Response to Theme	Quantitative cost estimates			Qualitative cost estimates		
					indication of time frame)	infrastructure, minor costs due to adaptation of vessels	
	General	1 to 17 billion USD per year	2030, OECD Europe	UNFCCC 2007			
		63.3 billion USD per year	2060s, Western Europe	Bosello et al. 2009			
Industry and tourism	Industry				Low (no indication of time frame)	Threats and opportunities, low coverage, no quantitative cost estimates available	UNFCCC 2007
	Financial sector				Low (no indication of time frame)	Threats and opportunities in insurance sector	
	Tourism				High (no indication of time frame)	Threats and opportunities, high costs in winter ski resorts	
Health	Summer heat and winter cold related deaths	0.01% of GDP	total Europe, +2.5°C	Agrawala et al. 2010	Low (2030, 2010-2050, 2060s)	Global cost assessments consider Europe not as vulnerable. Negative adaptation costs possible (less morbidity costs due to warmer	Bosello et al 2009, World Bank 2009, Ebi 2008,
		10-215	Up to 2030	Ebi 2008;			

Sector	Response to Theme	Quantitative cost estimates			Qualitative cost estimates		
		million € per year		Markandya and Chiabai 2009		climate).	Agrawala et al 2010
	Vector borne diseases						
	Water borne diseases						
	Air quality						
	Cold spells, benefits from avoided deaths	-0.7 billion USD per year in 2060s, Western Europe		Bosello et al. 2009	Negative	Avoided disease and mortality costs due to less cold stress	
Coastal areas	Losses to flooding	0.3-2.6 billion € per year	up to 2080s, EU27	PESETA	High (2030, 2060s, 2080s)		See also sector Water
		0.31% of GDP	total Europe, +2.5°C	Agrawala et al. 2010			
		624 to 1,785 million USD per year	2030, OECD Europe	UNFCCC 2007			
		5 billion USD	2060s, Western	Bosello et			

Sector	Response to Theme	Quantitative cost estimates			Qualitative cost estimates		
		per year	Europe	al. 2009			
		0.25-3.5 billion € per year		SOER 2010, PESETA 2009			
	Losses to salt intrusion						
	Beach nourishment, sea and river dikes	1.0 (0.9-1.2) B€/yr	2020s, Europe, A1B	Brown et al. (2011) (ClimateCost) Undiscounted costs, SLR and socio-economic change together			
		1.2 (1.0-1.3) B€/yr	2020s, Europe, E1				
		1.5 (1.2-1.7) B€/yr	2050s, Europe, A1B				
		1.0 (0.8-1.2) B€/yr	2050s, Europe, E1				
		1.6 (1.3-2.0) B€/yr	2080s, Europe, A1B				
		0.7 (0.5-0.8) B€/yr	2080, Europe, E1				
		0.5 (0.4-0.7) B€/yr	2020s, Europe, A1B	Brown et al. (2011)			

Sector	Response to Theme	Quantitative cost estimates			Qualitative cost estimates		
		0.6 (0.5-0.8) B€/yr	2020s, Europe, E1	(ClimateCost) Undiscounted costs, SLR/climate change only			
		1.1 (0.9-1.3) B€/yr	2050s, Europe, A1B				
		0.6 (0.4-0.7) B€/yr	2050s, Europe, E1				
		1.2 (0.9-1.7) B€/yr	2080s, Europe, A1B				
		0.5 (0.3-0.7) B€/yr	2080, Europe, E1				
Urban areas	Flooding				High (2010-2050)	Low coverage for inland flood protection costs, See sector Water	World Bank 2009
	Building and housing Infrastructure	0.18% of GDP 6-88 USD per year	total Europe, +2.5°C	Agrawala et al. 2010 UNFCCC 2007	Potentially by far the highest (2030, 2060s)	High uncertainty range – vulnerable proportion of new investment is estimated and the additional costs for climate-proofing this proportion.	UNFCCC 2007, Bosello et al 2009, Agrawala et al 2010
	Health				Low (2030, 2010-	See sector Health	

Sector	Response to Theme	Quantitative cost estimates			Qualitative cost estimates		
					2050, 2060s)		
	Water resources				Medium (2030, 2060s, up to 2080)	See sector Water	
	Telecom				High (2030, 2060s)	See “Infrastructure”, no specific adaptation cost estimates for Telecom and communication. For Energy, see sector Energy.	
	Energy, communication resources						

* Units: %GDP = percentage of Gross Domestic Product; € = Euro, USD = United States Dollars.

5 EU Policy Areas

In this section climate impacts in different EU policy areas are analysed. First, relevant climate and socio-economic scenarios are presented, followed by a literature review of the impacts of climate change. The assessment focuses on the effects of climate change within the European Union. The link between the impacts and European policies is established. The assessments form the basis on which the impact tables (part 4) are constructed. In order to use the most recent information we have been in contact with ongoing European research projects, so sometimes we refer to information that is not yet published.

5.1 Land-use and soil

5.1.1 Scenarios

In order to evaluate climate change impacts in Europe, scenarios on socio-economic developments and in particular land-use change are required. A large and increasing number of land-use scenario projects have been identified that all address specific problems10, including agriculture, forestry, and nature management and biodiversity. Here we highlight those that cover Europe as a whole and have been used in a climate change context. Urban sprawl is discussed in the section on urban scenarios. The EURURALIS project, initiated by the Netherlands government and running from 2004, presents an integrated impact assessment framework to support policy discussion about the future of Europe's rural areas. It uses the four SRES scenarios (Global Economy- A1, Continental Markets- A2, Global Cooperation- B1 and Regional Communities- B2) as inspiration to further develop and detail a toolbox with data and models to project changes in sustainable development indicators for European human well-being, ecology and economy issues (see Fig. 6).

5.1.2 Literature assessment on impacts

Introduction

In Europe, the dominant land uses are agriculture and forestry, which respectively cover 45% and 36% of the total land area. Both land use types have changed considerably during the last decades. Agricultural land use has declined by about 13% between 1961 and 2000 (Rounsevell et al. 2006), while the forested area has increased by some 900.000 ha per year between 2000 and 2010, an annual gain of 0.07% (FAO, 2010).

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[10] E.g., Grounds for Choices; ATEAM; ACCELERATES; EURURALIS; PRELUDE; ESPON; ALARM/ECOCHANGE; SCENAR2020; SENSOR; DeSurvey; FARO; PLUREL; OECD/FAO; SEAMLESS; LUMOCAP; from Rounsevell and Henrichs (2008) and Henrichs (personal communication)

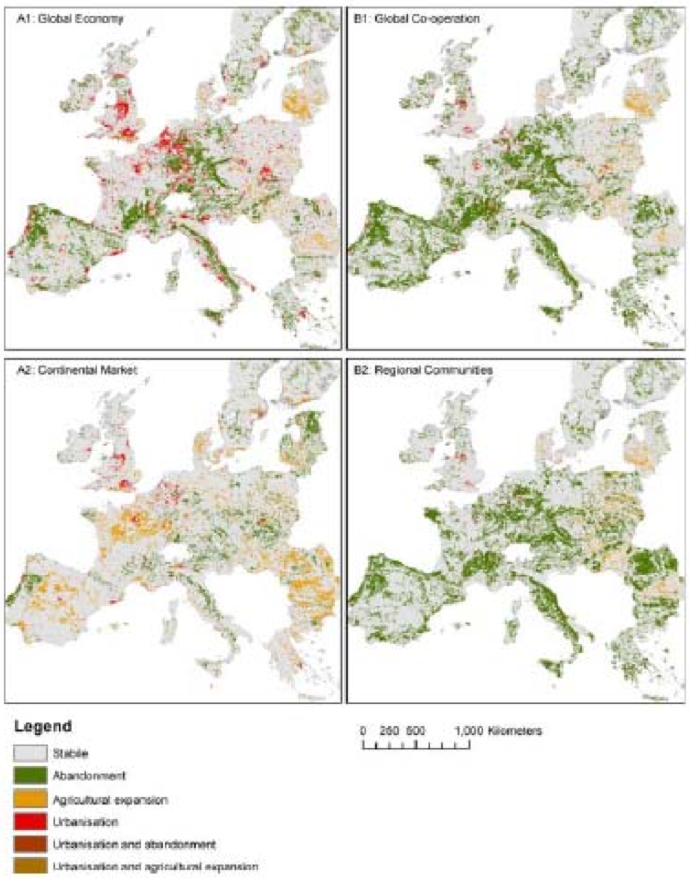


Figure 6: Example of the identification of hot-spots of land change using a multi-scale, multi-model approach (Verburg et al., 2010)

A large range of soil types exist across the European Union (for a soil map of the EU, see http://eusoils.jrc.ec.europa.eu/projects/soil_atlas/Atlas_Contents.html). Climate change possesses a variety of threats to various soil types in Europe. In its 2002 Communication 'Towards a Thematic Strategy on Soil Protection', the European Commission identified eight main threats to soils in Europe: erosion, decline in organic matter, contamination, salinization, compaction, soil biodiversity loss, sealing, landslides, and flooding. The Thematic Strategy stated that 'there is no conclusive evidence on the effects of climate change on soil, but it appears likely that it will increase the potential of the threats. This in turn suggests that soil protection will be of increasing importance in the future' (European Commission 2002).

The remainder of this section will focus on the effects of a changing climate on soils and land use in Europe. However, most literature focus on the reverse process: the effects of soils and land use changes on climate change. Therefore, this topic will shortly be discussed first.

A significant amount of literature regarding the effects of soils and changing land use patterns on climate change deals with the vast carbon stocks in European soils, especially in peatlands. Peat soils contain 20 % of the carbon in European soils, the rest is stored in mineral soils. The soil carbon stocks in the EU27 amount to approximately 75 billion tons of carbon; of this stock around 50% is located in Sweden, Finland and the United Kingdom because of the vast area of peatlands in these countries. The largest emissions of CO2 from soils in Europe result from land use change and in particular, drainage of organic soils. These emissions amount to 20-40 tons of CO_2 per hectare per year for a total area of 31,8 millions of ha in EU27 (Schils et al. 2008).

European legislation

In 2011, nine EU member states have specific legislation on soil protection (mainly related to contamination). Soil protection is addressed indirectly through different sectoral EU policies (for instance on water, waste, chemicals, industrial pollution prevention, nature protection, pesticides use, agriculture) (European Commission 2011). However, some progress has been made in the previous years, both in terms of policy development and the availability of information. The EU Thematic Strategy on Soil was announced in 2006 (EEA 2007). Its aim is 'to ensure that Europe's soils remain healthy and capable of supporting human activities and ecosystems'. The Thematic Strategy was accompanied by the Soil Framework Directive. The goal of the Directive is to oblige Member States to tackle threats such as landslides, contamination, soil erosion, loss of soil organic matter, compaction, salinization and sealing (Schils et al. 2008). The Thematic Strategy and the proposal for a Soil Framework Directive have been sent to other European Institutions to proceed in the decision-making process (European Commission 2011). To date, a majority of member states supports the EU strategy on soils. However, a minority of Member States opposes the strategy for various reasons (European Commission 2010) and this stops the strategy from being adopted and implemented.

The European Common Agricultural Policy (more extensively described in the section 'agriculture') is expected to have a positive effect on soils in Europe. This is a result of the introduction of cross compliance requirements related to the introduction of agricultural soil protection practices (European Commission 2006).

As soil degradation (e.g. erosion, desertification, melting of permafrost) is a transboundary issue, not only European legislation but also global legislation can influence land use and soil management. International programmes, such as the UN Convention to Combat Desertification (UNCCD), have fostered action to combat land degradation in affected countries in Europe through the implementation of national, sub-regional and regional action programmes (EEA 2007).

Socio-economic developments related to soils and land use

Based on the global storylines of the IPCC that are presented in the special report on emission scenarios (SRES), a range of future scenarios for the EU 15, Norway and Switzerland was developed, showing spatially explicit changes in land use. The scenarios include existing land use classes (e.g. urban, cropland, grasslands and forests) as well as new land use classes such as bioenergy crops. The most striking scenario outcomes are:

- a large decline in agricultural land use leading to abandoned agricultural land, resulting from assumptions about future crop yield developments with respect to changes in demand for agricultural commodities;
- increases in urban areas due to population and economic change in all scenarios, but with different spatial patterns;
- a slow increase in forest land area reflecting assumed policy objectives;

- an increase in area of bioenergy crops, with some scenarios assuming a major development of this new land use (Rounsevell et al. 2006).

Rounsevell et al. (2006) present the general, quantitative trends in land use changes for the four SRES scenario's in 2080 (Fig. 7). These trends show small increases in urban areas, large reductions in agricultural areas for food production (except for B1 and B2) partly compensated for by increases in bioenergy production, forest land and areas protected for conservation and/ or recreation with surplus land in the A1F1 and A2 scenarios.

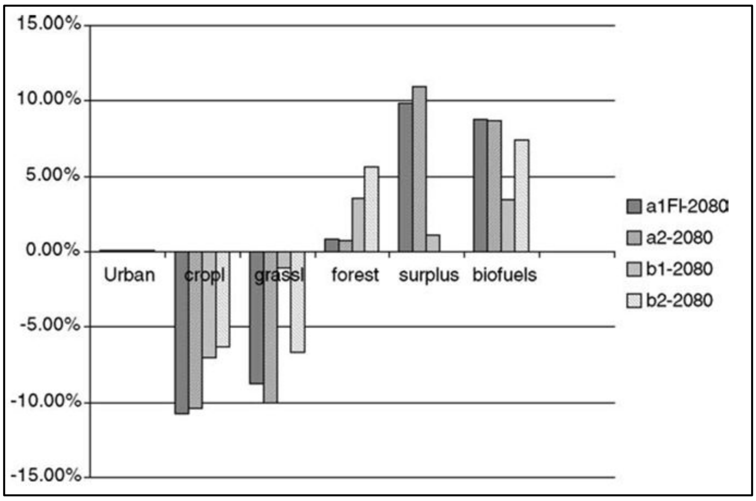


Figure 7: Aggregated land use change trends in 2080 for Europe for the A1FI, A2, B1 and B2 (HadCM3) scenarios (the y-axis represents the absolute area as a percentage of the

Urbanisation, tourism, transport, agriculture and industry are all sectors that apply particular pressures on soil resulting in erosion, desertification and contamination. Uncontrolled urban expansion (or urban sprawl that is widespread across Europe) may result in the unnecessary loss of good quality soil (EEA 2007).

Soil carbon storage

Soil carbon is a mixture of organic compounds with turnover times ranging from days to millennia. The overall change in soil carbon is determined by the balance between carbon inputs from photosynthesis and carbon losses through decomposition and hydrological processes, including erosion. Effect of climate change on soil carbon storage can be related to changing atmospheric CO_2 concentrations, increased temperatures and changing precipitation patterns.

The evidence of changes in soil carbon content as a result of increased atmospheric CO_2 concentrations is limited. However, a meta-analysis concludes that if results of various experiments are combined, a net increase in soil carbon of about 6% would be observed as a result of the climate change over the next 50 – 100 years, indicating an overall positive effect of elevated CO_2 on soil carbon input to soils.

Elevated temperatures have been shown in experimental studies to generally increase the rate of soil respiration and thereby the loss of soil carbon content due to increased decomposition rates. It is expected that the effects of increasing temperatures on decomposition have a higher and more sustained impact on soil carbon than the effects of temperature on plant production, due to the fact that soil respiration is more vulnerable to changes in temperature than photosynthesis and plant respiration. Increase in decomposition rates ranges from 15 to 45% in different studies across a range of habitats. The loss is thought to be greatest in northern latitudes as current decomposition processes are limited by low temperatures and permafrost. The consequence of loss of soil carbon will be a positive feedback to the climate system in the long term.

A more extreme hydrological cycle as a result of climate change will result in more extreme and frequent periods of soil moisture deficit. This will decrease the rate of decomposition in many systems but increase decomposition in waterlogged system such as peatlands, where much carbon is stored. Long term effects of repeated summer droughts vary; in a range of European shrublands, droughts were observed to either stimulate soil respiration rates by 40% or depress the rates by 30%, depending on initial hydrological conditions. Droughts in combination with higher temperatures could exacerbate the loss of carbon by erosion. Mediterranean countries have a relatively high risk of desertification as a result. In mountainous areas of central Europe, expected changes in rain event frequency and intensity may increase soil erosion. Flood events will partly remove eroded carbon from soils but as well redistribute the carbon across the landscape.

In general, there is no clear evidence for either an overall combined positive or negative impact of climate change on terrestrial carbon stocks. The management of land and soils overrules any impact on soil carbon from climate change (Schils et al. 2008).

Erosion

Several types of soil erosion can increase as a result of climate change. On a 'business as usual' basis, the European Environmental Agency expects and increase in erosion risks of 80% in agricultural areas in Europe, especially in places where erosion is already severe. Extreme precipitation events, melting of snow, high river discharge and increased droughts are all climate related events which influence soil degradation. Accelerated erosion by running water has been identified as the most severe threat to soil in Europe (Kirkby et al. 2004). Often however, these climate related phenomenon are not the only drivers of erosion. The types of land use, vegetative cover and land management contribute to a large extent to soil degradation (EEA, 2007). Although the Mediterranean region is historically the most severely affected by erosion there is growing evidence of significant erosion occurring in other parts of Europe (e.g. Austria, Czech Republic and the loess belt of Northern France and Belgium).

In more than one third of the total land of the Mediterranean basin, average yearly soil losses exceed 15 tons/ha (European Commission 2002). In this region, where droughts are expected to occur more often due to a changing climate, water and wind erosion can lead to increased degradation of land. While the abandonment of agricultural land and subsequent reversal of permanent vegetation may have contributed to reduced erosion rates, a lack of maintenance of terraces in mountain areas may have actually led to increased erosion (EEA 2007). In mountainous areas of central Europe, expected changes in the frequency and intensity of precipitation events may increase soil erosion (Schils et al. 2008).

Salinisation

Saline soils are expected to increase in coastal areas as a result of salt water intrusion from the sea side with rising sea levels and (periodically) low river discharges. Salinization alters soil quality and reduces crop yields, thereby reducing an area's capacity to produce food, which in turn has severe socio-economic implications (EEA 2007).

Landslides

Although there are multiple causes of landslides, landslides in Europe are most often the result of soil saturation with water from heavy rain fall events and snow melt. Landslides mainly have a local effect, and it is therefore difficult to make general statements about landslides on an European scale. Landslides result in soil loss in the case of shallow landslides, or soil transfer in other cases. Particular soil physical properties such as structure, bulk density, water permeability and retention capacity can be affected. This can subsequently result in loss of soil functions and an increase in the vulnerability of the soil to other threats, mainly erosion and compaction (Eckelmann et al. 2006).

5.1.3 Damage and adaptation costs

Table 5.1: Damage costs Land-use and soil

	2025		2080	
Sectors	**Estimated Damage Costs**	**Sources for Damage Estimates**	**Estimated Damage Costs**	**Sources for Damage Estimates**
Soil and land use	Low	Own estimate	Medium	Own estimate

Table 5.2: Adaptation costs Land-use and soil

Sectors	Themes	Adaptation costs (qualitative)	Sources	Notes
Soils and land use	Not available yet	Soils: Low Land use: High (indirect)		Soils: Low coverage, existence of adaptation measures questionable Land use: High costs for the inhabitants in case of resettlement

5.1.4 Summary

Summarizing- Main problems:

Effects of climate change on soil carbon storage can be related to changing atmospheric CO2 concentrations, increased temperatures and changing precipitation patterns. Increased temperatures generally increase the rate of soil respiration and thereby the loss of soil carbon content due to increased decomposition rates. The loss is thought to be greatest in northern latitudes as current decomposition processes are limited by temperature. However, there is no clear evidence for either an overall combined positive or negative impact of climate change on terrestrial carbon stocks. The management of land and soils overrules any impact on soil carbon from climate change. A more extreme hydrological cycle as a result of climate change will result in more extreme and frequent periods of soil moisture deficit. Droughts in combination with higher temperatures could exacerbate the loss of carbon by erosion. In mountainous regions, intense rainfall and floods will lead to soil erosion and redistribution of soil carbon. Saline soils are expected to increase in coastal areas as a result of salt water intrusion from the sea side with rising sea levels and (periodically) low river discharges. Landslides as a result of soil saturation with water from heavy rainfall and snow melt have mainly local effects in Europe, leading to loss of soil functions and increased vulnerabilities to erosion and compaction. In the short term (2050) important changes are expected concerning the state of European soils. In the longer term, it is expected that soils, provided that they are not disturbed by anthropogenic actions, will slowly adapt to climate change and move towards a new equilibrium. However, most soils in Europe are influenced by land management practices which overrule climate change effects.

Knowledge gaps:

More with respect to monitoring, refinement of methodologies for measuring both soil carbon stocks and fluxes is needed. A major gap is the lack of understanding and quantification of the impacts of freeze-thaw and drought-rewet events on soil carbon (Schils et al. 2008). Quantitative data about the costs of climate change related to soils and land use is hardly available. Also data about the social impacts related to soils and land use are lacking. Further, the economic and social impacts of specific land use changes and changing soil conditions are lacking.

Table 5.3: Summary table Land use and soil

Climatic driver or social economic driver	Sub-threat or opportunity	Time-frame	Area affected[1]	Potential environmental impacts[3]	Potential economic impacts[3]	Potential social impacts[3]	Level of agreement and evidence[2]	Reference
Rising atmospheric CO_2 concentrations Rising temperatures Changing frequency and intensity of rainfall events	Increase in soil carbon content Increase in decomposition rates with 15- 45% Increase in soil moisture deficits	2100	Especially northern latitudes European shrublands: ranging from 40% increase or 30% decrease in soil respiration rates Erosion in Mediterenean and Mountainous areas	Positive feedback to the climate system in the long term Desertification, removal and redistribution of soil carbon			Low/ Low	Schils et al. 2008
Rising air temperatures Changing frequency and intensity of rainfall events Types of land use, vegetative cover and land management	Soil erosion	2050	Increase of 80% erosion risks in agricultural areas Wind and water erosion in southwest Europe Mountainous areas in Central Europe	Desertification in dry areas- Major Removal and redistribution of soil carbon	Increased land degradation Increase investments in erosion prevention measures	Decreased rural incomes	Medium/ Medium	Schils et al. 2008; EEA 2007; Kirkby et al. 2004
Rising sea level Temporal low river discharges	Salinisation	2100	Coastal areas	Altered soil quality Changing natural vegetation towards more salt-tolerant	Reduced crop yields Technological development	Reduced incomes Cultivation of more salt-tolerant crops	Low/ low	EEA 2007

Climatic driver or social economic driver	**Sub-threat or opportunity**	**Time-frame**	**Area affected**[1]	**Potential environmental impacts**[3]	**Potential economic impacts**[3]	**Potential social impacts**[3]	**Level of agreement and evidence**[2]	**Reference**
				species				
Heavy rain fall events Increased temperatures	Landslides	2100	Very local effects	Soil loss in case of shallow landslides Soil transfer Changing soil structure, bulk density, water permeability and retention capacity Increasing vulnerability to erosion and compaction	Reduced crop yields	Damage to properties	Low/ Low	Ecklemann et al 2006

5.2 Agriculture

5.2.1 Scenarios

Early scenarios for European agriculture in a climate change context were developed in the context of the ATEAM project (e.g., Ewert et al.,2005; Rounsevell et al., 2006). The PESETA project addressed the potential impacts on crop yields in Europe on the basis of two GCMs and two SRES scenarios (A2 and B2, see Figure 8 for an example, Iglesias et al., 2009). The study also addresses adaptation options and adaptive capacity that would ameliorate the potential impacts. Other studies developed scenarios to determine the effects of future climates and socio-techno-economic developments for agricultural land use, combining models of crop growth and farm decision making to predict profitability over the whole of Europe (Audsley et al., 2006; Berry et al., 2006). They find that the main effects are expected in the agriculturally marginal areas of Europe, while the variations are much more determined by the economic scenarios than by climate change. Olesen et al. (2006) analyze a wide range of SRES scenarios and find that the variation in simulated results attributed to differences between the climate models were, in all cases, smaller than the variation attributed to either emission scenarios or local conditions, and that the methods used for applying the climate model outputs played a larger role than the choice of the GCM or RCM. Because of a longer growing season and higher CO2 concentrations, Olesen et al. (2006) find an increased thermal suitability for grain maize cultivation and strong increases in net primary productivity in northern Europe. Hermans et al. (2010) show that under a global market scenario agricultural productivity increases, while less agricultural land will be needed to supply the European demand for food. Productivity will concentrate in those regions which have a competitive advantage. This shows that non climate drivers play an important role in the development of the European agriculture.

In general the scenario studies focus on changes in land use and productivity. Next to climatic drivers, important drivers for the development of agriculture are social and economic changes, such as changes in consumption, technology development, urbanisation and globalisation. The impact of weather extremes on farm systems and productivity are not included in most scenario's.

The Commission periodically publishes outlooks for EU agriculture and rural areas in which it is observed that climate change will remain to influence the market outlook, with unpredictable weather patterns leading to supply fluctuations (EC-DG AGRI, 2010). The Scenar 2020 studies for DG Agri identified and analysed a number of long-term trends concerning the demographic developments in rural regions, the dynamics of rural areas and the future of the agricultural economy including the environmental dimension for the EU, in its planned and potential future geographical shape until 2020 (Nowick et al., 2006, 2010).

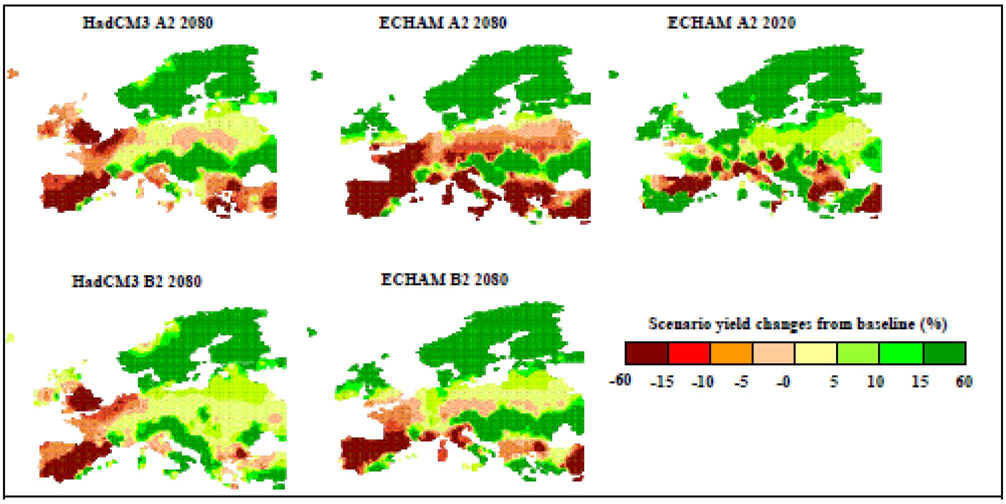


Figure 8: Crop yield changes under the HadCM3/HIRHAM A2 and B2 scenarios for the period 2071 - 2100 and for the ECHAM4/RCA3 A2 and B2 scenarios for the period 2011 – 2040 compared to baseline (Iglesias et al., 2009)

5.2.2 Literature assessment on impacts

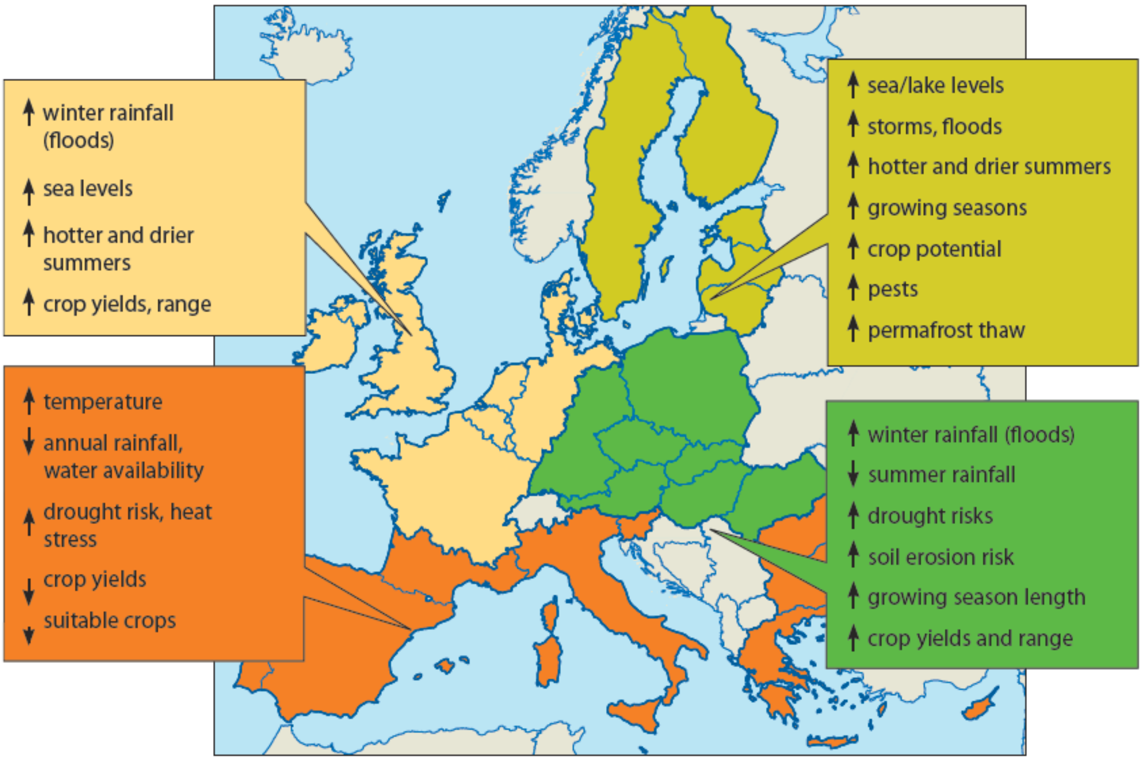
Introduction

Europe is one of the world's largest and most productive suppliers of food, including both arable crops and animal products. In 2008 Europe accounted for 19% of global meat production and 20% of global cereal production (Olesen et al. 2011). Due to the small proportion of total GDP and employment related to agriculture in Europe, the vulnerability of the overall European economy to changes in agricultural production is low. However, the local effects may be substantial (Maracchi et al. 2005).

Worldwide, the animal husbandry sector is a major player in greenhouse gas (GHG) emissions, accounting for 9% of anthropogenic CO2 emissions. The largest share of this can be attributed to land use changes caused by expansion of pastures and arable land for crops that produce animal feed. Livestock themselves are responsible for the emission of gases with a far higher potential to warm the atmosphere than CO2, namely CH4 (with 23 times the global warming potential- GWP- of CO2) and N2O (296 times the GWP of CO2) (Steinfeld et al. 2006).

Climatic conditions affect agriculture and the water resources needed to maintain stable production levels in many areas of Europe (Ciscar et al. 2009). Various authors distinguish between direct and indirect effects of increased greenhouse gas emissions on the agro-ecosystem. Direct effects are primarily due to higher CO2 levels and include increased biomass production and water use efficiencies. Indirect effects are related to climatic components such as temperature, precipitation, extreme events, radiation and humidity (Olesen and Bindi 2004) which in turn influence crop growth and occurrence of weeds, pests and diseases (Olesen et al. 2011). Changes in temperature, radiation, precipitation and CO2 concentration also impact plant water uptake (Supit et al. 2010).

When studying the effects of climate change on agriculture in Europe, most literature make a distinction between effects in Northern and Southern Europe. In Northern Europe, positive impacts of climate change on agriculture are expected. These are related to longer growing seasons, introduction of new crop species and varieties, higher crop production, and expansion of suitable areas for crop cultivation (Carter 1998). Positive effects on agriculture in the whole of Europe include a potential increase in CO2 fertilization of plants. In Southern Europe however, the benefits of projected climate change will be limited, while the disadvantages will be prevalent. Disadvantages include increased water demand and periods of water deficit, extreme weather events (heat, drought, storms), loss of soil carbon content, erosion, lower harvestable yield and higher yield variability, increased pesticide requirements and crop damages, and reduction in suitable areas of traditional crops (Olesen and Bindi 2004; Commission of the European Communities 2009; Maracchi et al. 2005).Rising sea levels may lead to a loss of farmland as a result of inundation and increasing salinity of soils and fresh water supplies, particularly in low-lying areas such as the Netherlands (Iglesias et al. 2009; Falloon and Betts 2010). Figure 9 gives an overview of the projected impacts of climate change in different European regions.



Source: European Union 2010

Figure 9: Projected impacts from climate change in different EU regions

Socio-economic characteristics also influence the vulnerability and adaptive capacity of the European agriculture. Impacts of climate change and variability largely depend on farm characteristics (e.g. intensity, size, land use). Farm characteristics influence management types and adaptation. As different farm types adapt differently, a large diversity in farm types reduces impacts of climate variability at regional level. Certain farm types may remain vulnerable while others will survive. These factors are often ignored in scenario studies (Reidsma et al., 2010). Farm management and adaptation can largely reduce the impact of climate change on crop yields and farmers income (Reidsma et al., 2010).

European legislation

European policies related to agriculture are presented in the Common Agricultural Policy (CAP). The CAP has been thoroughly revised in the last decade. The European Commission set the following three main objectives for the CAP after 2013:

1. To preserve the food production potential on a sustainable basis throughout the EU to guarantee long-term food security for European citizens and contribute to growing world food demand;
2. To support farming communities that provide the European citizens with quality and diverse food that is produced sustainably, in line with our environmental, water, animal health and welfare, plant health and public health requirements (this objective also includes climate change issues);
3. To maintain viable rural communities, for whom farming is an important economic activity creating local employment (European Commission 2010).

The reform of the CAP introduced a new system of direct payments, the Single Payment Scheme. The main aim of the single payment is to support farmers' incomes while farmers are encouraged to make their decisions based on market signals. In return, farmers have to respect standards in environmental protection, animal welfare, and food safety while maintaining the land in good condition.

Socio-economic developments related to agriculture

Socio-economic challenges which are likely to influence the European agricultural sector in the coming decades are competition for water resources, rising costs due to environmental protection policies, and competition for international markets (Iglesias et al. 2009). The future of European agriculture will be closely related to worldwide developments such as increasing world population, changing diets and increasing demands for biofuels. These are likely to compete with food production as limited land is available. There is a general expectation that world food prices will tend to rise in response to climate change (Commission of the European Communities 2009; Falloon and Betts 2010).

Crop productivity

Future projected trends in European agriculture include a northward movement of suitable zones for crops with increasing crop productivity in Northern Europe, and declining productivity in Southern Europe (Maracchi et al. 2005; Olesen and Bindi 2004; Falloon and Betts 2010). Increased crop productivity, especially for cereals and cool season seed crops in Northern Europe is due to lengthened growing seasons, decreasing cold spells and extended periods without frost. Yields could increase as much as 30% by 2050, depending on the crop (Olesen et al. 2011). However, the potential benefits in northern Europe will not always fully materialise due to various limiting factors (e.g. extreme events, soil degradation and insufficient water availability) (Maracchi et al. 2005). Negative impacts in Northern Europe include increased pests and diseases, nutrient leaching, and reduced soil organic matter. Various insects, for example the European corn borer (*Ostrinia nubilalis*) and the Mediterranean fruit fly (*Ceratitis capitata*), are expected to show a considerable northward expansion with rising temperatures (Olesen et al. 2011).

In contrast to Northern Europe, crop productivity is expected to decrease where seasonal precipitation decreases significantly such as in the Mediterranean and Southeast Europe. In these regions, yields could decline up to 30% by 2050. Furthermore, an increasing demand for water for crop irrigation (up to 10%) is likely to occur especially in Southern regions, as well as for fruit and vegetables in Northern Europe (Falloon and Betts 2010). Some crops that currently grow mostly in southern Europe will become more suitable further north or in higher altitude areas in the South. Projections for a range of emission scenarios show a 30-50% increase in suitable area for grain maize production in Europe by the end of the 21st century (Olesen et al. 2011).

The expectation is that by 2020, there will be small increases in European crop productivity (Commission of the European Communities 2009) and resultant yield improvements, particularly in Northern Europe, with the exception of some areas in central and southern Europe. The overall yield gain in the EU would be 17% in 2025. However, the predictions for 2080 differ depending on the scenario. For the scenario's which predict less warming, a small yield increase is predicted whereas for the 5.4ºC scenario the yield could decline with 10% (Ciscar et al. 2009).

According to Ciscar, et al. (2009) the estimated changes in GPD per region confirm the significant regional differences between Northern and Southern European countries. The effects on GDP are smaller than the productivity increases and consistent with the physical impact. They are positive in all regions except for Mediterranean countries. In Northern Europe the impact in terms of GDP is estimated to be between 0.8 and 1.1 per cent and the wefare change ranges between 0.6 and 0.7 per cent in 2080. In Southern Europe the changes in GDP rages in 2080 between -1.3 and -0.1 per cent and in terms of welfare loss between -1.0 and 0 per cent. The monetary estimates show that in all cases uncertainty derived from social-economic scenarios has a larger effect than uncertainties from climate scenarios. In this study is assumed that the yield is optimal given no limitations with respect to water availability, fertilizer and management. Economic losses as a result of weather extremes can be high. In 2003 the estimated economic losses to farming from the combined effects of droughts, heat stress and fires is estimated at 10 billion Euro.

Tol (2002) performed estimations for agricultural damage cost impacts. He estimated that the impact of a 2.5 °C global temperature rise is 0.55 percent of the Gross Agricultural Product (GAP) for OECD-Europe. The standard deviation is 1.03. With adaptation the rise of GAP will become 2.09 percent with a standard deviation of 1.12. For Central Europe and the former Soviet Union the GAP changes by 0.94 percent with a standard deviation of 1.19. With adaptation the gain for this region will rise to 2.65 percent of GAP with a standard deviation of 1.13 (Tol 2002).

Climate change is likely to affect crop production from region to region. A study by Parry et al. (1999) compered the HadCM2 with the HadCM3 scenario. Under a HadCM2 scenario the world is generally able to feed itself until 2080. Under the HadCM3 scenario the agricultural production is reduced, leading to increasing food prices and higher risk of hunger particularly in arid and sub-humid tropic areas (Parry et al. 1999). Food prices may increase by 45 percent in 2080. A scenario study by Fisher et al. 2002 found that the impact of climate change on the GDP (aggregated global level) is rather small. Between - 1.5 % and + 2.6 %

where found. These refer to a total GDP of agriculture in the reference scenario ranging from USD 2.9 – 3.6 trillion (at 1990 prices). In this study agriculture in Western Europe losses added value in all scenarios, Under the A2 scenario the loss is between 6 – 18 percent. The former Soviet Union gains up to 23 percent under A2 scenario (Fisher et al. 2002). Darwin et al. (1999) shared the conclusion that the economic impact of climate change on agriculture is relative small. He found the global impact of climate change within USD -24.5 billion to USD 25.2 billion a year when cropland expansion is allowed. When land use changes are not allowed the world GDP declines from USD 0.7 billion to USD 73.4 billion. In the European Community GDP drops by 0.3 to 1.1 percent (Darwin et al. 1999).

Agrawala et al. (2010) performed a global study on the impact of climate change and the costs and benefits of adaptation. This OECD study also used the DICE and RICE model and the WITCH model. For agriculture this study build on earlier studies by Tan and Shibasaki (2003), Rosenzweig and Parry (1994) and Nordhaus and Boyer (2000). According to Agrawala et al. (2010) the agricultural damages related to a 2.5 °C global temperature rise are 0.49 % of the GDP.

Extreme events

The intensity of extreme weather events such as periods of high temperature, heavy storms or droughts is predicted to increase in the coming decades. These extreme weather events can severely disrupt crop production and lead to a greater yield variability. Further they can lead to an increase in fires and pests damaging the crops (Maracchi et al. 2005). Periods of high relative humidity, frost and hail can further affect yield and quality of fruits and vegetables (Iglesias et al. 2009). In the Mediterranean region, where mostly permanent crops (olive, grapevine, fruit trees) are cultivated, extreme events such as hail and storms can severely reduce or completely destroy yields.

Livestock production

Livestock systems may both directly and indirectly be influenced by climate change. Therefore it is important to keep in mind that the effects as well as the technological measures differ between livestock in stables and free range livestock.

Direct influences of climate change include effects on animal health, growth and reproduction while indirect effects include impacts on the productivity of pastures and forage crops. Heat stress has several negative effects on animal husbandry, including reduced reproduction and milk production in dairy cows, and reduced fertility in pigs. This can negatively affect livestock production in summer in the warm regions of Europe. Technological developments can reduce the threat for livestock in stables as climate regulation can reduce the heat stress. During the cold period warming is likely to be beneficial for cooler regions due to reduced feed requirements, increased survival, and lower energy costs (Maracchi et al. 2005). The effects on grassland differ depending on the type. In general, intensively managed and nutrient-rich grasslands will respond positively to both an increase in CO_2 concentration and a temperature increase, given that water supply is sufficient. Nitrogen-poor and species-rich grasslands may respond differently to climate change and increases in CO_2 concentrations (Olesen and Bindi 2004).

5.2.3 Damage and adaptation costs

Table 5.4: Damage costs Agriculture

	2025		2080	
Sectors	**Estimated Damage Costs**	**Sources for Damage Estimates**	**Estimated Damage Costs**	**Sources for Damage Estimates**
Agriculture	Negative (North) to Medium (South)	Stern Review; Nordhaus Boyer 2000	Negative (North) to High (South)	Stern Review; Bosello et al 2009; PESETA; ADAM

Table 5.5: Adaptation costs Agriculture

Sectors	Themes	Adaptation costs (qualitative)	Sources	Notes
Agriculture	Productivity	Low (2.5°C scenario)	Agrawala et al 2010	Main measures: crop change and change in seeding/harvesting dates. Low coverage, but literature suggests benefits are higher than costs for most measures
	Damage due to floods	Medium (2030, 2060s)		See sector Water, but no estimates specific to flood adaptation in agriculture available

	Damage due to water scarcity	Medium (2030, 2060s, up to 2080)	Fischer et al 2007, Bosello et al 2009, Agrawala et al 2010	See sector Water. Low coverage, but literature suggests benefits are higher than costs for most measures. More estimates are given for developing countries, incl. Eastern Europe
	Damage due to droughts			
	Damage due to diseases and pests	High (no indication of time frame)		Possibly costly measures available (R+D, chemical protection), but low coverage for adaptation cost

5.2.4 Summary

Summarizing main problems

Climate change and variability effect agricultural production and farm income. Effects of climate change on local economies in Europe may be substantial. Climate change and variability differs throughout Europe and for different farm systems. In general higher temperatures seems to advantage crop yields in Northern Europe, whereas high temperatures and persistent dry periods during summer will limit crop production in southern Europe. Weather extremes associated with damages as droughts and extreme rainfall are likely to occur more often. Droughts can also negatively influence livestock production due to heat stress, while higher temperatures in Northern Europe limit the costs for heating livestock stables. Increasing yield variability as a result of pests and diseases and severe storms is expected. Farm management and adaptation can largely reduce the impact of climate change on crop yields and farmers income.

Knowledge gaps

Most research related to agriculture and climate change focuses on crops, while effects on livestock may be substantial as well. More research into the effects of climate change on livestock is therefore needed. In scenario studies not much attention is paid to extreme weather events. Extreme events can play an important role in production damages. Scenario studies often ignore social economic conditions and farm management. Since effects of climate change differ between regions, there is need for increased attention on regional studies of impacts of climate change. There is also a considerable need to better estimate the costs of various adaptation measures.

Table 5.6: Summary table Agriculture

Climatic driver or social economic driver	Sub-threat or *opportunity*	Time-frame	Area affected[1]	Potential environmental impacts[3]	Potential economic impacts[3]	Potential social impacts[3]	Level of agreement and evidence[2]	Reference
Rising air temperatures and CO2 concentrations	Lengthened growing seasons Decreasing cold spells Extended periods without frost	2050	Northern Europe	Northwards movement of suitable zones for crops, e.g. cereals Increased need for fertiliser and pesticides	Increased crop productivity, thus increased yields (up to 30% in 2050, depending on the crop). 30- 50% increase in area suitable for maize production in 2100 Changes in optimal farming systems	Increasing rural incomes Relocation of farm processing industry	Medium/ high	Maracchi et al. 2005; Olesen and Bindi 2004; Falloon and Betts 2010; Iglesias et al. 2009
Rising air temperatures and CO2 concentrations	Increased production	2080	Northern Europe		Rise of 0.8 – 1.1 % of GDP		Low	Ciscar et al, 2009
Rising air temperatures and CO2 concentrations	decreased production	2080	Southern Europe		Fall of up to 1.3 % of GDP		Low	Ciscar et al, 2009
Rising air temperature by 2.5 °C global temperature rise	Increased production	+ 2.5 °C global temperature rise	OECD-Europe		0.55%GAP without adaptation 2.09% GAP with adaptation		Low	Tol 2002
Rising air temperature by 2.5 °C global temperature rise	Increased production	+ 2.5 °C global temperature rise	CEE&fSU-Europe		0.55%GAP without adaptation 2.09% GAP with adaptation		Low	Tol 2002

Climatic driver or social economic driver	Sub-threat or *opportunity*	Time-frame	Area affected[1]	Potential environmental impacts[3]	Potential economic impacts[3]	Potential social impacts[3]	Level of agreement and evidence[2]	Reference
Rising atmospheric CO_2 concentrations	Potential increase in CO_2 fertilization by plants	2100	Whole of Europe		Increased crop productivity	Increasing rural incomes	High/ high	Olesen and Bindi 2004; Commission of the European Communities 2009; Maracchi et al. 2005;
Rising air temperatures Decreased precipitation	Droughts Heat stress of livestock	2050	Mediterranean and Southeast Europe	Desertification in dry areas- Major Soil degradation- Major Increasing demand for water for crop irrigation (up to 10%) in southern regions Increasing demand for irrigation for fruit and vegetables in northern Europe	Yield decline up to 30%, depending on the crop Need for new varieties and cultivation methods Reduced reproduction and milk production dairy cows Reduced pig fertility Need for climate regulation technologies	Increasing competing claims for water Loss of rural income Land abandonment	Medium/ high	Falloon and Bet 2010; Maracchi et al. 2005; Iglesias et al. 2009
Rising air temperatures Increased precipitation	Pests and diseases		Northern Europe	Increased use of pesticides may lead to environmental pollution	Production losses Increased costs of pesticides Costs for research& development to mitigate pests and diseases (major)	Increased risk of health problems Loss of rural incomes	Medium/ medium	Olesen et al. 2011; Iglesias et al. 2009
Increased number and intensity of wind	Severe storms	2050		Increased erosion rates	Disruption of crop production	Damage to properties	Medium/ medium	Maracchi et al. 2005; Iglesias et

Climatic driver or social economic driver	**Sub-threat or *opportunity***	**Time-frame**	**Area affected[1]**	**Potential environmental impacts[3]**	**Potential economic impacts[3]**	**Potential social impacts[3]**	**Level of agreement and evidence[2]**	**Reference**
and precipitation					Greater yield variability			al. 2009

5.3 Forestry

5.3.1 Scenarios

Scenarios for forestry in Europe in a climate change perspective often focus on the effects of forest management strategies and/or climate change on carbon stocks and flows, such as analyses of the European Forest Institute. In the analyses, climate change is projected to increase carbon stocks and net carbon sequestration compared to current climatic conditions (Karjalainen et al., 2003). Between 2005 and 2010, about 870 million tonnes of CO2 have been removed from the atmosphere by photosynthesis and tree biomass growth in European countries. This corresponds to about 10 percent of the greenhouse gas emissions in 2008 of these countries (Michelak et al, 2011).Based on three contrasting scenarios, the European Forest Sector Outlook Study (UNECE/FAO, 2005) presents long term trends for supply and demand of forest products and services and outlook to 2020 in western and eastern Europe and also notes the potential for mitigation. Even taking into account the large uncertainties, for the forestry sector in Europe, climate change may offer opportunities for the forestry sector by higher productivity and northward shifts of tree species. Climate change on the other hand may reinforce damage by drought, fire storm and insect calamities (Michelak et al, 2011)Forestry is also linked to climate impacts and human health through forest fires affecting air quality (e.g., EEA, 2006).

5.3.2 Literature assessment on impacts

Introduction

There are 1.02 billion hectares of forests in Europe, Which amount to 25 percent of the world total (Michalak, 2011). European forests can be divided into Boreal (85%, located in the European part of the boreal zone), Temperate (11%, divided into Atlantic and Continental depending on the availability of soil water in Central Europe) and Mediterranean (4%, in the Mediterranean basin) (Figure 10). European remains one of the most important producers of roundwood in the world. Non-wood goods can be an important source of local income. The value of market non-wood goods represents 15 percent of the value of marketed roundwood in countries that reported both values. Marketed services can be a source of significant income for private and public landowners (Michelak et al, 2011). The forest sector can play an important role in climate change mitigation through carbon sequestration and substitution of non-renewable energy and materials. At the same time forests must adapt to a changing climate (Michelak et al, 2011). Almost 4 million people work in the forestry and forest based industries. Forest sector employment is still decreasing (Michelak et al, 2011) More than 20% of European forests are managed primarily to provide non-timber ecosystem services such as water and soil protection, and protected forests now amount to 5% of total forest area in Europe (Maracchi et al. 2005).

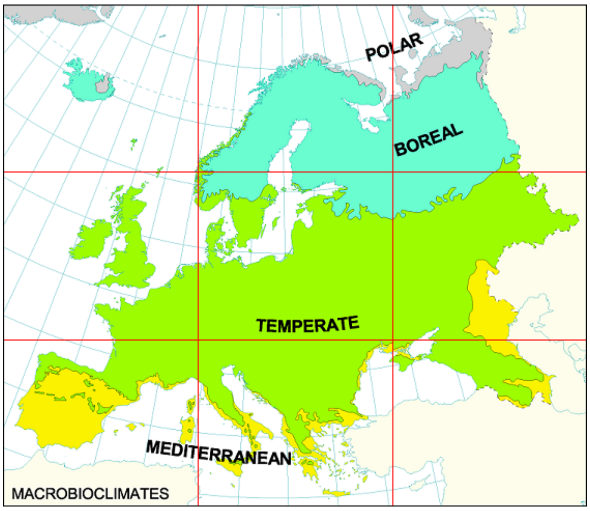


Figure 10 Bioclimates in Europe. Source: www.globalbioclimatics.org (2009)

Figure 11 gives an overview of cover of forests and other wooded area in the EU member states.

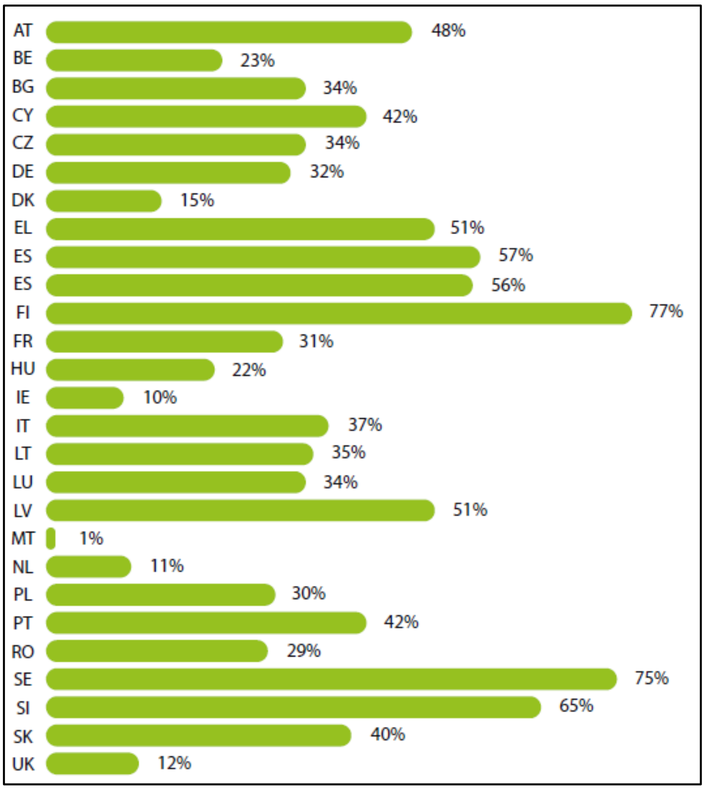


Figure 11: Forest and other wooded area cover in the EU Member States as a percentage of the total land area. Source: European Commission Directorate-General for Agriculture and

Over the past centuries, land clearance in Europe has led to significant deforestation. Since 1800 afforestations started again, and the total area has increased (with fluctuations). In the past 20 years, forest area in Europe has increased by some 0.8 million hectares each year (Michalak et al, 2011). 13 Million hectares are established. Production of wood and productivity from European forests is increasing.

Climate change is expected to have various complex effects on European forests, at least in the mid to long term (Lindner et al. 2010). Forests and the way they are managed are particularly sensitive to climate change because the long lifespan of trees does not allow a rapid adaptation to environmental changes (European Commission 2010). Effects of climate change include increased risk of biotic (pests and diseases) and abiotic (droughts, storms and fires) disturbances to forest health. However, the exact effects of climate change on forests are complex and not yet well understood. The impacts of climate change will vary throughout the different geographic regions of Europe, with forest fires likely to dominate in southern Europe and the limited diversity of tree species in boreal forests enhancing the risk of significant pest and disease impacts. Next to negative climate change impacts, especially in the long term, opportunities arise as well in the forestry sector. Evidence to date suggests that productivity in northern and central Europe has increased and is likely to continue to increase. Further, northward expansion of potential distribution of some tree species is expected and potentially more favourable conditions for summer recreation in mountainous regions will exist (Lindner et al. 2010). However, with more drastic changes in climate towards the end of the 21th century, severe and wide ranging negative climate change impacts have to be expected in most European regions (Lindner et al. 2008), with the Mediterranean region as the most vulnerable to climate change based on potential impact assessment and adaptive capacity (Lindner et al. 2010).

European legislation

On 15 December 1998, the European Council adopted a Resolution on a Forestry Strategy for the European Union. This was a reaction to the growing concern about the coherence between forest policies of the member states and forest-related activities at the EU level, as well as the rising profile of forests in international policy debates and initiatives on sustainable development (European Commission 2012). As a reaction to this, an EU Forest Action Plan was developed in 2006, spanning the period 2007- 2011. At the moment the forest strategy is under revision. The review process should lead to a comprehensive and holistic discussion on the objectives and common values of forests, forestry and the forest sector in the EU. On 18 February 2011 the Standing Forest Community (SFC) decided to set up a working group for exchanging ideas about the future EU Forestry Strategy.

The current objective of the EU Forest Action Plan is to support and enhance sustainable forest management and the multifunctional role of forests (European Commission 2006). Sustainable forest management guarantees forest multi-functionality. This approach contributes to the objectives of the Europe 2020 strategy, which is to generate more growth using fewer resources and to reach a low carbon economy in the future by sustainable management of natural resources (European Commission 2010).The objective of the working group is to make recommendations on how the forest strategy can ensure coherence with other polices or instruments and add value at EU level.

Socio-economic developments

The socio-economic adaptation capacity related to the forest sector has rarely been analysed in the EU. Forest ownership structures, the availability or shortage of forest sector work force, and the educational level of forest workers are factors influencing the adaptive capacity in the forest sector. There are considerable differences in socio-economic adaptive capacity of the forest sector within Europe. The adaptive capacity is smallest in the Mediterranean region where the most severe impacts of climate change on forestry are expected. As a consequence, vulnerability in this region is larger compared to the rest of Europe. In northern Europe, in the long term vulnerability to climate change and related extreme events increases the more dependent the region is on employment related to the forestry sector, e.g. reindeer husbandry in Scandinavia. However, globalisation and other socio-economic changes often supersede vulnerability to climate change. An important economic factor influencing European forestry is global timber trade. The impact of climate change on timber trade flows to and from Europe is difficult to predict since it is expected that the major tropical forest basins will undergo a drastic change in the longer term.

Changes in productivity

The combination of rising CO2 concentrations in the atmosphere and increasing temperatures result in changing productive patterns of forests and shifting distribution of forest biomes.

In Northwest Europe, where water supplies are not a limiting factor, growth rates are likely to be enhanced by a combination of rising CO2 levels in the atmosphere, warmer winters and longer growing seasons, and increased nutrient availability as a result of atmospheric deposition and increased soil mineralisation (Lindner et al. 2010). Maracchi et al. (2005) state that the climatic zone suitable for boreal forest can be enlarged by 150- 550 km due to rising (winter) temperatures. As a consequence, timber yields may increase in northern Europe in the mid to long term with 8-22%, depending on climate scenario and species. Also, the accumulation of carbon in biomass will be enhanced (Lindner et al. 2010). However, higher winter temperatures will shorten the period with frozen soils and snow cover. This results in a reduced availability of timber due to inaccessibility of forest resources outside the frost period, which will pose a threat to the industry (Lindner et al. 2008; Maracchi et al. 2005). Projections of the development with the model EFISCEN, show that for all projected climate scenarios, climate change resulted in an increased forest growth, especially in Northern Europe. In southern Europe increased precipitation in spring and increased water use efficiency of trees as a result of higher CO2 concentrations compensate for increased summer droughts (Eggers et al., 2008). Sarres et al (2011) state that climate change will lead to more severe growth reduction, three mortality and damage from forest fires on *Pinus Halepensis Miller* in the Mediterranean.

In mountainous regions, a temperature- induced upward shift of the tree line will improve protection against natural hazards by stabilizing soils and erodible mass and reducing runoff peaks. For highly specialized alpine plant communities the upward shift of the tree line ecotone is a substantial threat. However, in managed forests where human interventions strongly affect the biodiversity, increased competitiveness of species-rich broadleaved forest communities can increase biodiversity.

Tol (2002) performed estimations for Forestry. He based his calculations on a study of Perez-Garcia et al, 1996. He estimated that the impact of a 1 °C global temperature rise and CO2 fertilization is 134 million USD for OECD-Europe. For Central Europe and the former Soviet Union the impact is negative. The damage costs are 136 million USD.

Droughts

The increase in productivity in Northern Europe contrasts with Southern Europe as the positive effects of a rising temperature on tree growth could be counteracted by limited water availability. Despite the fact that CO2 enrichment is likely to increase water use efficiency, more frequent and severe summer droughts may negatively influence forest stands. Droughts resulting from increased (summer) temperatures and (possible) reduced summer precipitation are likely to lead to reduced productivity and more extensive forest fires, especially in the already fire-prone Mediterranean areas, but also in the Temperate Continental and Boreal regions (Lindner et al. 2010; Maracchi et al. 2005). According to Allen et al. (2010) increases in frequency, intensity and duration of drought and heat stress could fundamentally alter composition, structure and biogeography of forests in many regions. Of particular concern are potential increases in tree mortality associated with climate-induced physiological stress and interactions with other climate-mediated processes such as insect outbreaks and wildfire (Allen et al., 2010). While small to medium fires have little or no negative impacts, more severe fires can cause significant damage to forests stands and ecosystems (Lindner et al. 2008). Ultimately, droughts can lead to desertification in some areas in Southern Europe. As extended droughts have much more drastic consequences on tree growth and survival than gradual changes in average climatic conditions, climate variability is of particular importance in this respect (Lindner et al. 2010).

Pests and diseases

Estimates of the possible influence of climate change on insect infestation are uncertain due to complex interactions between forests, insects and climate (Maracchi et al. 2005). However, studies show that a changing climate will have an impact on both temporal and spatial dynamics of pest species. Increasing temperatures and altered patterns of precipitation influence the frequency and intensity of forest pest and pathogens species as well as their spatial distribution, size and geographical range. This can result in serious damage to both protected forests and those used for timber production. Norway spruce and pine forests as well as forests stands of oaks are expected to be most affected by biotic disturbance agents. As these tree species are of high economic importance, a higher probability of damage might put European forests at risks (Lindner et al. 2008). Wolf et al. (2008) studied the effects of background herbivory by insects on vegetation growth and production with the GUESS model framework. Temperature rise is likely to enhance the potential insects impact on vegetation. The impacts are strongest in eastern parts of Europe, where potential insect damage to *Betula pubescens* (Downy Birch) can increase by 4–5%.

Regions that represent northern or upper distributional limits, such as the Alps or the Boreal zone, will probably be most affected by an increase in stability and population density of certain pest species. Central and Northern European forests will be increasingly predisposed to fungal diseases that benefit from longer growing seasons associated with higher temperatures. In turn, the increased amounts of precipitation during summer as expected for Northern Europe can support the spread of fungal diseases. In eastern Europe, more frequent occurrence of warm and dry years could promote pest and pathogen development. It is likely that the present distributional range in the southern part of Europe will become too warm for certain species, not only resulting in northward and upward shifts but also leading to a decrease in species. The probability of the establishment of exotic species will increase (Maracchi et al. 2005).

Adaptation costs dealing with pests and diseases are estimated to be high while there is a low availability of funds for adaptation costs. Research and development in chemical protection to find methods to prevent outbreaks and protect forests against them are likely to be very costly (European Commission 2010).

Storms

Windthrow and other storm damage is most relevant in Central, Western and Northern Europe. It is uncertain whether the frequency of Atlantic storms will increase in the future. However, local thunderstorms may be more intense and damage may be greater in combination with water saturated soils and decreased soil freezing which reduces stand stability. The economic impacts of wind damage are 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 (Maracchi et al. 2005).

5.3.3 Damage and adaptation costs

Table 5.7: Damage costs Forestry

	2025		2080	
Sectors	**Estimated Damage Costs**	**Sources for Damage Estimates**	**Estimated Damage Costs**	**Sources for Damage Estimates**
Forestry	Negative	Tol 2002	Negative (North) to High (South)	ADAM

Table 5.8: Adaptation costs Forestry

Sectors	Themes	Adaptation costs (qualitative)	Sources	Notes
Forests	productivity	Low (no indication of time frame)	EFI et al 2008	Main measures: change in planted trees and change in seeding/harvesting dates. Low coverage, but literature suggests benefits are higher than costs for most measures
	Damage due to fires	Medium (no indication of time frame)		Main measures: Technical Monitoring systems and forest aisles
	Damage due to pests	High (no indication of time frame)		Possibly costly measures available (R+D, chemical protection), but low coverage for adaptation cost
	Damage due to storms	Medium (no indication of time frame)		Main measures: forest aisles, change in planted trees

5.3.4 Summary

Summarizing main problems

With more drastic changes in climate towards the end of the 21st century, severe and wide ranging negative climate change impacts on the forestry sector are expected in most European regions, with the Mediterranean region as the most vulnerable to climate change. Forest fires are likely to dominate in southern Europe and the limited diversity of tree species in boreal forests enhance the risk of significant pest and disease impacts. Extreme storm events are likely to increase in north, west and central Europe, leading to economic losses in managed forests. Rising temperatures and CO2 concentrations on the other hand increase forest productivity in northern Europe and lead to changing distribution of certain forest biomes.

Knowledge gaps

The socio-economic adaptation capacity related to the forest sector has rarely been analysed in the EU. Literature on (northward) spread of pests and diseases is virtually absent. It is unknown if increased growth due to higher CO2 levels will outweigh drought effects in forest productivity. Further, quantitative data to describe the environmental, ecological and social effects of climate change on the forestry sector are very site-specific due to ecological and socio cultural diversity. Therefore it is difficult to give a generalized overview of these effects at EU-level. Regional studies focussing at the impacts, adaptive capacity and adaptation are necessary.

Table 5.9: Summary table Forestry

Climatic driver or social economic driver	Sub-threat or *opportunity*	Time-frame	Area affected[1]	Potential environmental impacts[3]	Potential economic impacts[3]	Potential social impacts[3]	Level of agreement and evidence[2]	Reference
Rising air temperatures Rising atmospheric CO_2 concentrations	*Changing biomes distribution* Decreased period with frozen soils and snow cover	2050- 2100	*Enlargement of climatic zone suitable for boreal forest by 150- 550 km* *Extension of growing season and higher photosynthesis in northern latitudes* *Growth of forest in mountainous areas currently limited by temperature*	Changing tree species distributions in north Europe Northwards and upwards (mountains) expansion of broadleaved deciduous species Increasing threats for specialized plant communities Thermophilic plant species become more common, while cold-tolerant species decline In large areas of western and central Europe, indigenous conifers may be replaced by deciduous trees	*Higher timber yields in northern latitudes (e.g. 8-20% increase depending on climate scenario and species)* Limited accessibility of forest areas outside the frost period	Increasing incomes in forestry sector in northern Europe	Medium/ Medium	EC 2006; Maracchi et al. 2005; Lindner et al. 2010
Rising air temperatures Rising atmospheric CO_2 concentrations	*Productivity and market changes*	1 °C global temperature rise and CO2 fertillization	*OECD-Europe*		134 million USD per year		Low	Tol, 2002
Rising air temperatures Rising atmospheric	*Productivity and market changes*	1 °C global temperature rise and CO2	*CEE&fSU*		- 136 million USD per year		Low	Tol, 2002

Climatic driver or social economic driver	Sub-threat or *opportunity*	Time-frame	Area affected[1]	Potential environmental impacts[3]	Potential economic impacts[3]	Potential social impacts[3]	Level of agreement and evidence[2]	Reference
CO_2 concentrations		fertillization						
Rising air temperatures Decreased precipitation	Droughts	2050	Decreased productivity in Central and Southern Europe due to decreased summer precipitation Increased fire risk in southern and central Europe, particularly in difficult to combat mountainous terrain Decreased tree growth in Mediterranean mountain ranges, the Alps and Carpathians	Desertification in dry areas- Major Soil erosion due to fires which enhance hydrophobicity and reduce plant regeneration- Major	Decreased forest productivity (e.g. 4-16% production losses in Germany for dry scenario)- Major Increased fire events will reduce wood production and decrease timber values- Major	Increasing competing claims for water Temporal replacement of inhabitants	Medium/ Medium	Maracchi et al. 2005; Lindner et al. 2008; Lindner et al. 2010
Rising air temperatures Increased precipitation	Pests and diseases	2100	Throughout Europe: Survival of exotic species in west, south and central Europe, pest and pathogen development in East Europe, expansion of insect herbivores and fungal diseases in North central and West Europe	Increased abundance of exotic species may lead to competition with indigenous species Increased loss of natural vegetation (major) Increased use of pesticides may lead to environmental pollution	Production losses (major) Increased costs of pesticides Costs for research& development to mitigate pests and diseases (major)	Increased risk of health problems	Medium/ Medium	Maracchi et al. 2005; Lindner et al. 2008; European Commission 2010
Increased number and intensity of wind	Severe storms		North, west and central Europe.	Loss of natural habitat Increased erosion rates Decreased water quality due to	Yield reductions in recoverable timber (major) Increased costs of unscheduled thinning and clear-cuttings	Damage to properties	Low/ Low	Maracchi et al. 2005

Climatic driver or social economic driver	Sub-threat or *opportunity*	Time-frame	Area affected[1]	Potential environmental impacts[3]	Potential economic impacts[3]	Potential social impacts[3]	Level of agreement and evidence[2]	Reference
				suspended materials	Problems in forestry planning			

5.4 Biodiversity and nature management

5.4.1 Scenarios

The biodiversity analysis of EURURALIS took into account the effects of land-use change, climate change, fragmentation by major roads, area of unfragmented patches, nitrogen deposition, forestry and disturbance. Results show that biodiversity is projected to decrease between now and 2030 in most countries for all scenarios, indicating that it is unlikely that the EU will be able to fulfil its commitment to stop biodiversity loss by 2010. This is mainly due to urbanization and increase in stress factors, and outweighs the area increase of nature arising from land abandonment (Verboom et al., 2007). Verburg et al. (2010) used multimodel multilevel approach to analyze a series of different scenarios of land use change in rural Europe for the period 2000–2030. In the ALARM project, the vulnerability of ecosystem service supply in Europe was analyzed in the broader context of global change (e.g., Schroter et al., 2005). ALARM also included an extreme scenario in which the thermohaline circulation would collapse. In ALARM, new scenarios for socio-economic drivers behind biodiversity loss were coupled to SRES climate runs, e.g. in the BAMBU (Business As Might Be Usual), GRAS (Growth Applied Strategy) and SEDG (Sustainable European Development Goal) scenarios.

5.4.2 Literature assessment on impacts

Introduction

There is a growing international awareness that sustainability of human society depends on services provided by ecosystems, and that these services are threatened by loss of biodiversity. Climate change has additional large impacts on the functioning of ecosystems and populations and it is expected to become the greatest driver of global biodiversity loss together with land-use change (Thomas et al, 2004; Lovejoy and Hannah, 2005; Millennium Ecosystem Assessment 2005).

European policy documents such as the 6th Environment Action Program (EC, 2002) and the White paper on Climate Change Adaptation (EC 2009), recognise the need to conserve biodiversity and to ensure adaptation of biodiversity to climate change. In the White paper, a framework is set out to enhance the EU’s resilience to the impacts of climate change.

For biodiversity and ecosystems, it is increasingly recognised that ecosystems are, on the one hand, threatened by climate change, but on the other hand, are part of the adaptation solution (‘green adaptation’) as they perform important services for society such as climate regulation, carbon sequestration, protection against flooding and avoidance of soil erosion. To fulfil these services, resilient ecosystems are needed, that are able to cope with the impacts of climate change.

European legislation

The Birds Directive (79/409/EEC) and Habitats Directive (COM/88/0381) form the cornerstones of the European biodiversity policy. An important obligation arising from the two directives is the designation of special protection areas and special areas for conservation, jointly referred to as the Natura 2000 sites. In these sites Member States have to ensure that the necessary management measures are taken in order to keep or restore the species and habitats for which the sites were designated in a favourable conservation status. The Natura 2000 network has been implemented for the long-term protection of biodiversity in Europe and now consists of approximately 18% of the total European EU27 territory.

Additionally the two Directives call for the protection of biodiversity by arranging the legal protection of a large number of species outside the Natura 2000 sites and by regulation of hunting of particular species in order to conserve and restore biodiversity in the wider EU countryside.

Influence of climate change on biodiversity

Climate change has two major impacts on biodiversity in Europe (1) Suitable climate zones shift northwards and to higher altitudes and species need to track this by colonizing new suitable habitats. It has been suggested that these effects can be compensated for by increasing spatial cohesion (see review Heller & Zavaleta (2009). (2) Weather extremes increase the population fluctuations of species and thus increase the regional extinction probability. However, it is still unknown how big the population fluctuations caused by weather extremes (or increased weather variability) will be under the different climate change scenarios and no studies exist that underpin the effectiveness of adaptation measures to dampen these effects. Nevertheless, support in literature is clearly growing that increasing habitat heterogeneity and connectivity of habitats might be an effective adaptation strategy to reduce the impacts of increased weather variability (e.g. Piha et al. 2007; Hodgson et al. 2009; Oliver et al 2010). Species that are most vulnerable include specialists, those at the top of the food chain, those with latitudinal and altitudinal restrictions and those with poor dispersal abilities (EEA, 2008).

Furthermore climate change has considerable impacts on the abiotic conditions of ecosystems, which might or might not be mitigated by management measures at the site or site surroundings, e.g. eutrophication, changes in the water cycle, sea level rise, shorter snow cover (EEA, 2008, 2010).

The latest estimates by the Intergovernmental Panel on Climate Change (IPCC 2007) are that 20-30% of species are at high risk of extinction with a 2-3°C increase in temperature. Suitable climate zones of species are shifting northwards and vertically (cf. results of FP5 project GLORIA) as a result of climate change. Range expansions have already been reported for many species from various taxa (e.g. Parmesan and Yohe 2003; Root et al 2003). Projections based on bio-climate envelope modelling have been developed for Europe for several species groups as birds, amphibians and reptiles, mammals, plants and butterflies. These projections predict much further shifts of at least several hundreds of kilometres for many species in the 21st century (Huntley et al. 2007). An assessment of the impact of climate change on the biodiversity of the Natura 2000 network (AEA 2009) showed that depending on the most severe scenario around 80 percent of all Natura 2000 sites will face temperatures 2-3°C higher towards the end of the century However, under the less severe scenario (B1) 67% of all sites, may experience a temperature increase of 1-2°C. Additionally the vulnerability of Habitat and Birds species to climate change was assessed. For 2011 a study has been commissioned by DG Environment that will develop ‘Guidelines on dealing with the impact of climate change on the management of Natura 2000’.

Ecosystem services

Ecosystems worldwide provide services for society. TEEB (2009) values different ecosystems around the world but gives no indication how climate changes influences these values. According to TEEB ecosystem services can reduce the impact of climate change. In Vietnam coastal vegetation reduces potential damage from storms and tidal swells. Planting mangroves along a part of the coastline in Vietnam cost USD 1.1 million but saved USD 7.3 million. In the Netherlands natural processes are used to improve coastal defence, for example through sand suppletion (Deltacommision, 2008)

Invasive species

Climate change influences the likelihood of successful invasions of species. The suitable climate zones shifts northwards and to higher altitudes. This means that suitable habitats can arise for invasive species. Near the edges of suitable climate zones disruption of ecosystems as a result of weather extremes might make native species particularly vulnerable for invasive species. The increased international movements in trade and tourism also play a role in distribution of invasive species. A suitable climate is one of the conditions for a successful establishment.

Economic impacts

Tol (2002) performed estimations for the damage costs of ecosystems. He based his calculations on a study of Frankhauser (1995) and Manne et al. (1995). He estimated that the impact of a 1 °C global temperature rise and CO_2 fertilization is negative for al ecosystems. The damage for OECD-Europe is calculated at 14.7 million Euros. For Central Europe and the former Soviet Union the estimated damage costs are 5.4 million USD.

5.4.3 Damage and adaptation costs

Table 5.10: Damage costs Biodiversity and Ecosystems

	2025		2080	
Sectors	**Estimated Damage Costs**	**Sources for Damage Estimates**	**Estimated Damage Costs**	**Sources for Damage Estimates**
Biodiversity and Ecosystems	Uncertain		Uncertain	

Table 5.11: Adaptation costs Biodiversity and Ecosystems

Sectors	Themes	Adaptation costs (qualitative)	Sources	Notes
Biodiversity and ecosystems	Shifting habitat zones Population fluctuations Abiotic changes	Medium to High (2030)	UNFCCC 2007 Parry et al 2009	Low coverage, estimates are more of a "educated guess" (UNFCCC 2007) Estimates are higher than for health, coastal zones, Severe distinction problems from non-adaptation costs

5.4.4 Summary

Summarizing main problems

Biodiversity is already declining because of human expansion and will be more at risk due to rising temperatures and changing precipitation patterns which lead to northward moving of suitable climate zones for species. Environmental quality will change negatively as a result of climate change, leading to salinization and eutrophication. A higher frequency of extreme events such as droughts and floods may lead to increased danger of extinction of local populations. Loss of ecosystems may lead to a loss of ecosystem services.

Knowledge gaps

The information of the economic damage of lost ecosystems is limited. There are economic key numbers of the economic value of ecosystems, but there are not yet calculations of how these values will change under climatic changes. There is little information on the impact of climate change on the establishment of invasive species. There is little information on the impact of weather extremes on the fluctuation and recovery of populations and effective adaptation measures.

Table 5.12: Summary table Biodiversity and nature management

Climatic driver or social economic driver	Sub-threat or opportunity	Time-frame	Area affected[1]	Potential environmental impacts[3]	Potential economic impacts[3]	Potential social impacts[3]	Level of agreement and evidence[2]	Reference
Atmospheric CO2	Eutrophication and Acidification	2050	All Europe	Loss of quality & decrease in habitat area	NA	NA	High/high	**EEA, 2008**
Precipitation	Water stress	2050	All Europe but Southern Europe is most vulnerable	Decrease of range and size of species populations Loss of quality & decrease in habitat area	NA	NA	Medium/medium	**EEA, 2008**
	Waterlogging	2050	All Europe	Decrease of range and size of species populations Loss of quality & decrease in habitat area	NA	NA	Medium/medium	**EEA, 2008**
Sea level rise, precipitation, droughts and river discharge	Increased salinity and habitat loss through see level rise	2050	Coastal areas	Loss of quality & decrease in habitat area	NA	NA	Medium/medium	**EEA, 2008**
Temperature	Shift in suitable climate zones	2000	All Europe	Latitudal and longitudinal movement of species. Decrease of range and size of species populations. Loss of quality & decrease in habitat area. This affects: A1 scenario: 80 % of N2000 areas (2-3 C) B1 scenario: 67 % 0f N2000 areas 20 – 30 % op species globally are at the risk of extinction with a 2-3 degrees temp. rise	NA	NA	High/high	**IPCC, 2007,** **GLORIA project,** **Parseman and Yohe 2003,** **Root et al 2003** **Huntley et al, 2007** **AEA, 2009** **Heller and Zavaleta, 2009**

Climatic driver or social economic driver	Sub-threat or opportunity	Time-frame	Area affected[1]	Potential environmental impacts[3]	Potential economic impacts[3]	Potential socia impacts[3]	Level of agreement and evidence[2]	Reference
	Reduced period of snow cover /melting of glacier ice	2020	Northern Europe and mountain areas	Loss of quality & decrease in habitat area	NA	NA	High/high	**EEA, 2008**
Temperature rise and CO2 furtillization	Impact to ecosystems	1 °C global temperature rise and CO2 fertillization	OECD-Europe		- 14.7 millions USD		Low	**Tol 2002**
Temperature rise and CO2 furtillization	impact to ecosystem	1 °C global temperature rise and CO2 fertillization	CEE&fSU		- 14.7 millions USD		Low	**Tol 2002**
Wind, precipitation, temperature	Extreme events (heat, droughts, storms, hail, fires)	2050	All Europe	Increase in population variation and increase in risk of extinction	NA	NA	High/high	**Piha et al, 2007** **Hodgson et al 2009,** **Oliver et al, 2010** **EEA 2008**

5.5 Fisheries and Aquaculture

5.5.1 Scenarios

IFPRI (2003) and FAO (2004) analyzed the prospects for global fisheries and aquaculture in a scenario analysis up to 2015. FAO also commissioned a scenario study for European fisheries by 2030 (Failler et al., 2007), analyzing the changes in fish consumption in the member states. Possible constraints posed on fisheries by climate change are not taken into account in these scenario studies.

5.5.2 Literature assessment on impacts

Introduction

Climate change has multiple impacts on fisheries and aquaculture production, including changes in primary production, species growth, recruitment, mortality, distribution, migration patterns, species composition of fish stocks, seasonality and productivity of marine and freshwater systems as well as increasing input costs. Such impacts are likely to increase in intensity with time (Fluharty, 2011; FAO COFI 2011). These impacts can be both positive and negative.

Climate change adds to a number of pressures already faced by fish stocks such as fishing mortality, loss of habitat, pollution, disturbance and invasive species (Brander, 2010). An estimated 88% of European fish stocks are already over fished (World Ocean Review, 2010), consequently making them less resilient to climate change. Additional losses to European fish stocks will have immense socioeconomic consequences on the fishing industry and European society (Seas at Risk, no year).

Adapting to climate change will be a major challenge for the European fisheries sector in the years to come. Climate change is an added stress to marine ecosystems and fish stocks. Changes ripple through the ecosystem and ultimately affect the resilience of the entire ecosystem. Substantial impacts of climate change on marine life are already apparent. For example, in the North Atlantic, distributions of fish and plankton are shifting northward (Beaugrand et al., 2002; Perry et al., 2005; Brander 2006; Jennings & Brander 2010).

European legislation

The Common Fisheries Policy (CFP) is the principal EU fisheries policy. One of its main objectives is to promote management of EU fishing fleets in order to reduce the negative impacts of fisheries on the environment. It also aims to contribute to the overarching European environmental objectives and in particular the Marine Strategy Framework Directive (MSFD). In 2009, the European Commission began a process to reform the CFP. After assessment and analysis of future policy scenarios, the European Commission is expected to make legal proposals for a reformed policy (EC, 2010a). The main conservation instrument of the CFP is restrictions to fish catches through total allowable catch levels (TAC) or quotas, restrictions on fish effort and fishing gear, plus the use of minimum landing size, closed areas and closed seasons. Distribution shifts may lead to a greater mismatch between the biological stock structure and management areas or management regulations

This is particular relevant if a stock or species will become available in another management area for only a part of the year, leading to an allocation problem of the TAC among countries. The establishment of species in a management area may attract fisheries to start exploiting before management regulations are in place (Rijnsdorp et al. 2009). Changes in productivity may alter fishing restrictions (Rijnsdorp et al. 2009).

It will be essential to integrate climate change adaptation and adequate risk management strategies for fisheries into the existing maritime regime (i.e. the Integrated Maritime Policy, the Maritime Strategy Framework Directive and the reform of the Common Fisheries Policy) as well as to make use of adequate policy instruments such as maritime spatial planning and integrated coastal zone management. Climate change adaptation and risk management strategies will include new rules for the redistribution of fisheries rights that reflect shifts in the geographical range of fish stocks as well as agreed rules of access to emerging stocks to prevent the development of illegal, unreported and unregulated fishing (IUU fishing).

Socio-economic developments

Fish production primarily serves direct human consumption (77% of global production in 2006), followed by non-food products such as fishmeal and fish oil. Global per capita fish consumption has steadily increased since the 1960s from 9.9kg to 16.4kg in 2005, as per capita food consumption has also been rising over the last few decades. In Europe, as of 2008 fish provided more than 11% of total animal protein supplies, compared to 7.6% in North and Central America and 19% in China (FAO, 2008).

Fish consumption greatly varies across countries and regions reflecting different eating habits. For example, demersal fish (fish occupying the sea floor) are often preferred by consumers in Northern Europe and North America, whereas cephalopods (inkfish) are more often preferred in Mediterranean and Asian countries. In industrialized countries, human populations are becoming older, richer, more educated and more health conscious. Demand for fish, viewed as a food that promotes health and well-being, has therefore grown (FAO, 2008).

It is generally agreed that the fishing industry is in a state of severe decline. Impacts to the fishing industry include reduced fishing opportunities, increased illegal fishing, and decreasing profitability resulting in a high level of government subsidy for the sector (EEA, 2010).

Acidification

Ocean acidification is a direct effect of anthropogenic CO_2 emissions. The ocean absorbs approximately 25% of the CO2 added to the atmosphere from human activities each year, greatly reducing the impact of greenhouse gas on the climate (Orr et al., 2009). Ocean acidification refers to the ongoing decrease in pH levels of the oceans caused by increased CO_2 in the atmosphere and in turn carbonic acid in the ocean (Conover, 2007). Current changes in ocean carbon chemistry are at least 100 times more rapid than any other changes over the last 100.000 years (OSPAR 2011).

The decrease in pH primarily affects ‘marine calcifiers’ such as corals and molluscs which impairs their ability to build skeletons and shells of calcium carbonate. This not only decreases their ability to grow by causing them to shift efforts away from productive actions to maintain calcification, but results in the loss of habitat for other marine species, which often depend on such structures through different stages of life (Conover, 2007), therefore indirectly effecting fisheries.

Moreover, acidification impacts planktonic primary producers which leads to negative impacts on food sources throughout the food web for various commercial species (Herr and Galland, 2009).The direct effect on other species such as harvested fish is less known. But it is believed to cause physiological diseases including acidosis of tissues leading to impaired metabolic functions. It is also expected that increased acidification is more severe for eggs and larval stages, thus reducing the levels of fish reproduction (Conover, 2007).

Europe is currently at the forefront of ocean acidification research. The EPOCA project documents this phenomenon and investigates its impacts on biological and biogeochemical processes. Emerging national projects like the German project “Biological Impacts of Ocean ACIDifiation” (BIOACID), the UK Collaborative NERC/Defra “Ocean Acidification Programme” and a few additional research efforts are relevant to ocean acidification (ESF, 2009).

Arctic region

In September 2007 the record low ice cover of the Arctic region was recorded, and was about half the size of normal minimum extent in the 1950s. The increased temperature of the ocean and air are reducing the coverage of sea ice in the Arctic polar region leading to biological and physical changes in many marine ecosystems (EEA, 2010).

With less summer ice coverage of the Arctic, fisheries gain access to these open waters and will also follow species as they migrate northwards to waters that are the appropriate temperature. The impact on fisheries is not clear because it is hard to predict how species will react to these ecosystems changes and whether annual plankton booms will coincide with growth of larvae and young fish (EEA, 2010).

Ocean stability and currents

Ocean water absorbs large amounts of CO_2 and rapidly transfers it to deeper water. Whereas surface-ocean currents are generally driven by the wind, deep-ocean convection currents are driven by high salinity and low temperature gradients (World Ocean Review, 2010). Rising temperatures can increase ocean stratification and decrease ocean mixing. These changes could influence the plankton and food web (Herr and Galland, 2009). A further result could be a rapid increase in the number of areas without oxygen with fatal consequences for living creatures (World Bank, 2010).

Rising ocean temperatures

Oceans have already absorbed 80% of the heat added to the climate system (IPCC, 2007). Even small changes in water temperature can have large impacts on the ocean environment (Love, 2010). Warmer ocean temperatures impact biodiversity by affecting the distribution of marine organisms, and consequently food web dynamics. Ocean temperature changes occur faster on continental shelves inhabited by commercially desirable fish, threatening the commercial fisheries industry (Seas at risks, no year).

All species, including fish, are adapted for life within a relatively moderate temperature range. Thus, below optimal temperatures slow the rate of metabolism and can eventually be lethal. Temperatures above the optimal range increase species’ metabolisms, while at the same time warmer water has less dissolved oxygen. The result is a thermal threshold called the ‘temperature oxygen squeeze’ where respiratory demand exceeds the capacity for oxygen intake. Water temperature is therefore an influential factor in determining the geographic range of a species. Minimum winter temperatures and maximum summer temperatures thus determine the high latitude and low latitude limit of a species (Conover, 2007 citing Portner and Knust, 2007).

Within regions there is a complex web of species adapted to colder or warmer thermal temperatures. The species are connected through a complex ecosystem that influences their abundance. Therefore, loss of a species, due to northward migration to other temperature zones, can cause great disturbances within the ecosystem (Conover, 2007).

Rising ocean temperatures may also positively or negatively affect the overall primary productivity (i.e. the production of organic compounds) of ecosystems which in turn will lead to effects on fish populations (Conover, 2007 citing Behrenfeld et al 2006).

Sea level rise

Since 1961 global average sea level has been rising - since 1993 it has been rising at an accelerated rate (FAO, 2008a). Sea level rise is caused by rising water temperatures which leads to thermal expansion. This is accelerated by additional water as glaciers, ice caps and ice sheets melt due to rising atmospheric temperatures (EEA, 2010).

Effects of sea level rise include increased shoreline erosion, higher storm surges and flooding, inhibition of primary production and reduction in water quality. Increased shoreline erosion, caused by storm surges and flooding, leads to damage or loss of critical habitat and infrastructure for fisheries and aquaculture production. Many of the world’s corals could drown, with serious consequences for species associated with coral reefs (World Bank, 2010). An estimated 90% of global fishery activity occurs in coastal waters (World Ocean Review, 2010).

Effects on the fishing industry

As described above, climate change will have diverse effects on fish species and marine ecosystems, ranging from loss of habitat and induced migration to increased illness and loss of metabolic functions. However, responses to climate change will differ between species as well as between stocks across a geographical distribution area (RECLAIM, 2010), making it difficult to make concrete predictions about impacts to the fishing industry. Nevertheless, it is expected that these effects are likely to have both positive and negative impacts on the productivity and seasonality of fisheries (Nikolova, 2010). Overall, it is estimated that there will be a decline in current gross revenues of up to 50 percent (about $80 billion per year) from the world’s fisheries caused by severe climate change and overfishing (World Bank, 2010). Replacing the predicted loss in gross revenues due to climate change globally will require an endowment in the hundreds of billions of dollars. Above all, developing countries are predicted to suffer most of the estimated losses. And according to the World Bank’s paper, the losses in gross revenues from high seas’ fisheries will be very high (ebd.).

Changes to ecosystems (i.e. migration of species to other areas), may lead to ‘new’ stocks and opportunities for the fishing industry, which will require new rules for the distribution and access to these stocks (Nikolova, 2010). However, the primary concern is that climate change, combined with other pressures on the industry, will reduce fishing opportunities and decrease landings and therefore industry profitability, which may result in increased government subsidies for the sector (EEA, 2010). A decline in the industry would therefore also likely lead to a decrease in employment in the sector. Illegal fishing activities may therefore increase as fishermen seek to maintain catch levels and fish outside of established fishing zones (EEA, 2010). Distribution shifts may also lead to changes in unintended by-catch (Rijnsdorp et al. 2009).

The migration of some species due to warmer ocean temperatures and the opening of Arctic waters in summer months may increase travel distances to fishing grounds, thus raising fuel costs and time at sea for fishing vessels. Other related effects may be increased tensions in the Arctic regions as fishermen seek to gain access to new fishing grounds before management of the region is resolved.

Research on climate and fisheries

Measures to assess the possible effects of climate change on European fisheries have been made and include the 2009 DG Mare report on the Economics of Climate Change Adaptation in EU Coastal Areas and the EU funded research project RECLAIM – Resolving climate impact on fish stocks. The RECLAIM project provides extensive research and is one of few projects (also FAO (2008a) Climate Change for Fisheries and Aquaculture) focusing primarily on climate impacts to fisheries. It is a compilation of long-term data sets to relate patterns of change in marine systems/fisheries to climate variability and critically assess our ability to forecast effects of climate change on future productivity and distribution. Another project is "Climate Change and European Fisheries", commissioned by the European Parliament. Further research has been done regarding the changes of the abundance and distribution of fish population, and a range of models have been developed to predict these effects (Brander, 2010; Perry et al., 2010; Planque et al., 2010). Significant progress has been made in modelling the effects of climate change on the population dynamics of individual species (Kell et al., 2005).

Additionally, various reviews (e.g. World Ocean Review, 2010; IUCN) exist which focus on the impacts of climate change on the ocean and not just fisheries. Other reports (e.g. Love, 2010) focus on the general state of the fishing industry including all threats such as overfishing.

Many reviews (i.e. EEA, 2010; Love, 2010; RECLAIM) take a regional approach to assessing the impacts of climate change on marine waters. This is relevant to assess climate change impacts on fisheries due to regional differences between impacts. For example, climate change induced species migration or acidification varies between regions.

5.5.3 Damage and adaptation costs

Table 5.13: Damage costs Fisheries and Aquaculture

	2025		2080	
Sectors	**Estimated Damage Costs**	**Sources for Damage Estimates**	**Estimated Damage Costs**	**Sources for Damage Estimates**
Fisheries and Aquaculture	Uncertain	ADAM	Uncertain	ADAM

Table 5.14: Adaptation costs Fisheries and Aquaculture

Sectors	Themes	Adaptation costs (qualitative)	Sources	Notes
Fisheries and Aquaculture	Fish stocks	Medium to High	World Bank 2010, EPOCA	Annual direct adaptation cost for Europe for fisheries: between $ 0,27 to $1,12 billion (mild scenario).The loss in gross revenues, household income, and the endowment required to offset the losses over time increases from the short term (2010-19), peak in the mid-term (2020-49) under all climate change scenarios and with a 5 percent discount rate. High uncertainties with cost estimation.
	Acidification	Medium to high	Cooley, S. & Doney, S. 2009, EPOCA, BIOACID	No estimates for Europe available yet. The only study available is from the US. This study of US commercial fishery revenues concerning adaptation costs caused by acidification is focusing on molluscs. It forecasts substantial revenue declines, job losses, and indirect economic costs.

5.5.4 Summary

Summarizing main problems

Climate change can impact all sea species and their interactions: primary production, individual growth, population growth, migration, mortality and so on. This leads to an increase in the uncertainty about the state of the fish stocks. The northward shift of species has already become apparent in empirical studies. Ocean acidification due to CO2 uptake threatens calcifiers such as shellfish and coral, and most likely also affects plankton and fish eggs and larvae. Rising temperature may lead to less ocean mixing and thus to lack of oxygen in higher strata. To the fisheries industry a loss of fish productivity may lead to lost revenues and increased distances to fishing grounds.

Knowledge gaps

There are no scenario studies for fisheries and aquaculture. Interactions in the food web are hard to predict; for example it is unknown how plankton blooms will coincide with growth of larvae and small fish.

Table 5.15: Summary table Fisheries and aquaculture

Climatic driver or social economic driver	Sub-threat	Time-frame	Area affected[1]	Potential environmental impacts[3]	Potential economic impacts[3]	Potential social impacts[3]	Level of agreement and evidence[2]	References
Acidification (increased atmospheric CO_2)	Prevents the process of calcification	Average decrease in pH of 0.1 units since the start of the industrial revolution; if the atmospheric CO_2 concen-tration reaches 650 ppm by the year 2100, a decrease in the average pH value by 0.30 units can be expected compared to pre-industrial values (WGBU 2006)	Arctic and Black sea are substantially high	Loss of habitat Damage to food web Decreased reproduction in larger species Severe effects on calcareous organisms	Decreased landings	Job loss Loss of cultural ties to fishing industry Significant loss of source of diet for Arctic indigenous	High	EEA, 2010; FAO (COFI), 2011; OSPAR, 2011
Loss of Arctic ice coverage	Sea-level rise	in the summer in coming decades	Arctic region, especially Region I (transition between the Boreal and the tru Arctic biogeographic zones)	Sea ice disappears	New regions open to fishing Higher fuel costs	Longer travel distances for fishermen	High	EEA, 2010; OSPAR, 2011
Ocean stability and currents	Reduced uptake of CO_2; harmful algal blooms	Slowdown of circulation in the 21st century is very likely	Specific habitats affected by lower salinities (e.g. Norwegian trench)	Slowdown of circulation			Medium	OSPAR, 2011
Rising ocean temperature	Shelf sea stratification and onset of the associated bloom; harmful algal blooms; non-indigenous species	The North-Atlantic have warmed since 1994 at a greater rate than the global mean. Prediction: strongest warming in Region I of the N-Atlantic	Most rapidly in the Baltic and North Seas (e.g. German Bight)	Northward shift in the distribution of plankton and both bottom-dwelling and pelagic fish species	Increased distance to fishing grounds (raise in input costs); increase of disease for farmed species of fish and shellfish	Job loss	High	EEA, 2010; FAO (COFI), 2011; OSPAR, 2011; ACIA 2005

Climatic driver or social economic driver	Sub-threat	Time-frame	Area affected[1]	Potential environmental impacts[3]	Potential economic impacts[3]	Potential social impacts[3]	Level of agreement and evidence[2]	References
Sea-level rise (thermal expansion combined with melting ice)	Coastal erosion Habitat loss for marine species	Global sea level rose on average at 1.7 mm/yr through the 20th century, a faster rate was evident in the 1990s; in the North-Atlantic: between 0.18 and 0.59 m by 2100;	Coastal and shoreline areas – enhanced by land activities such as urbanisation and agriculture Most threatened Member States are Ireland, Spain and Portugal	Coastal erosion Habitat loss for marine species Decrease in water quality for coastal aquaculture	Decreased landings	Job loss	High	EEA, 2010; OSPAR, 2011

5.6 Freshwater resources: floods, droughts and water quality

5.6.1 Scenarios

Currently large areas of Europe, in particular in Southern and South-East Europe, are vulnerable to water scarcity and drought events Climate change will increase this risk which results in social, economic and environmental losses. Climate change will also intensify the hydrological cycle, resulting in an increase of the magnitude and frequency of extreme precipitation events in many parts of Europe and more frequent and intense floods. Over the last decade floods have been significant natural hazards in Europe in terms of economic losses. This is also due to increasing number of people, wealth and economical activity located in flood prone areas. The damages caused by floods are expected to increase in the future.

Scenarios for possible future pathways help to understand the range of the expected changes as a basis for sustainable water resources management and to avoid the severe consequences for people living in flood prone, water scarce or water stressed areas as well as for their aquatic ecosystems. These scenarios provide a reference point for long-term strategic planning and allow to test water plans against uncertainties and surprises which are inherently embedded in a longer term strategic planning process.

There is a number of national and regional climate change scenarios, that also consider the impact of future climate on water resources, mainly precipitation (e.g., UKCP'09[11] for UK, KNMI 06[12] for the Netherlands, 2C scenarios for Denmark[13], CIRCHE[14] for the Mediterranean, Alps[15]).

Three recent projects (PESETA, SCENES and ClimWatAdapt) cover the whole EU. SCENES and ClimWatAdapt are specifically dedicated to the impact of climate change on water–related hazards in different sectors,

The SCENES project is a 4-year project developing and analyzing a set of comprehensive scenarios for Europe's freshwater futures up to 2050. It covers all of "Greater" Europe reaching to the Caucasus and Ural Mountains, and including the Mediterranean rim countries of north Africa and the near East. In the context of the SCENES project four scenarios have been developed together with stakeholders from the 27 member states for calculating future water withdrawals and land-use changes: Economy First, Policy Rules, Fortress Europe and Sustainability Eventually. These scenarios will be quantified to complement the storylines with numerical information about key issues.

The *Economy First* scenario envisages a central role for globalisation and liberalisation, encouraging new technologies and innovations (Figure 12) This story line results in significant water quality deterioration and a decrease of water availability by 2025, but the

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[11] http://ukclimateprojections.defra.gov.uk/

[12] http://www.knmi.nl/klimaatscenarios/knmi06/index.php

[13] http://www.dmi.dk/dmi/dkc06-02.pdf

[14] http://www.circeproject.eu/index.php?option=com_frontpage&Itemid=1

[15] http://www.eea.europa.eu/publications/alps-climate-change-and-adaptation-2009

market mechanisms partially restore the balance between water demand and water availability by 2050. There is substantial inequality between different geographical regions in this scenario.

The *Policy Rules* scenario assigns a stronger role to the policies at EU level, but policies gradually become more ineffective and as a result, ecosystem services begin to deteriorate significantly up to 2030. Around 2030, climate change impacts become very intense and this leads to increased public participation and a high level of public/private partnerships in 2050, allowing the harmonisation of water demand in accordance with water availability.

In the *Fortress Europe* scenario a number of crises, such as energy, financial, and climatic crises, lead to increasing instability and terrorist activities and as a result Europe closes its borders. The perceived threats keep the EU together. Europe concentrates on security issues and self-sufficiency, with a strong focus on water demand management. In this way water demand is largely satisfied by 2050.

The *Sustainability Eventually* depicts one environmentally sustainable Europe with a strong focus on quality of life. The success of initially top-down policies transforms the policy landscape, which becomes very much local oriented and based on bottom-up, slow change measures. By 2050 environmental (also water related) issues are dealt with by ecoregion and not by country, Water scarcity and drought problems are in general less severe than in present, with only a few “hot-spots” left.

The climate projections along these pathways have been performed with the WaterGAP model and IPCM4 and MIMR regional climate models. For this project, the climate change scenarios developed in the ENSEMBLES[16] project are used, and the hydrological data are generated with the LISFLOOD model from JRC.

The most recent European scenario work for fresh water resources has been performed in the ClimWatAdapt project for the water-dependent sectors agriculture, domestic use, manufacturing, electricity production, navigation, tourism, and aquatic ecosystems for 2025 and 2050. This project covers the 27 EU Member states. The scenarios are based on Regional Climate Model (RCM) runs driven by the outputs of different GCMs using the IPCC SRES A1B emission scenario. The project used the SCENES scenarios, but with bias-corrected climate datasets, provided by JRC, where JRC’s hydrological rainfall-runoff-routing model LISFLOOD[17] was forced by the bias-corrected output from 11 GCM-RCM model combinations.

[16] http://ensembles-eu.metoffice.com/index.html

[17] http://floods.jrc.ec.europa.eu/lisflood-model

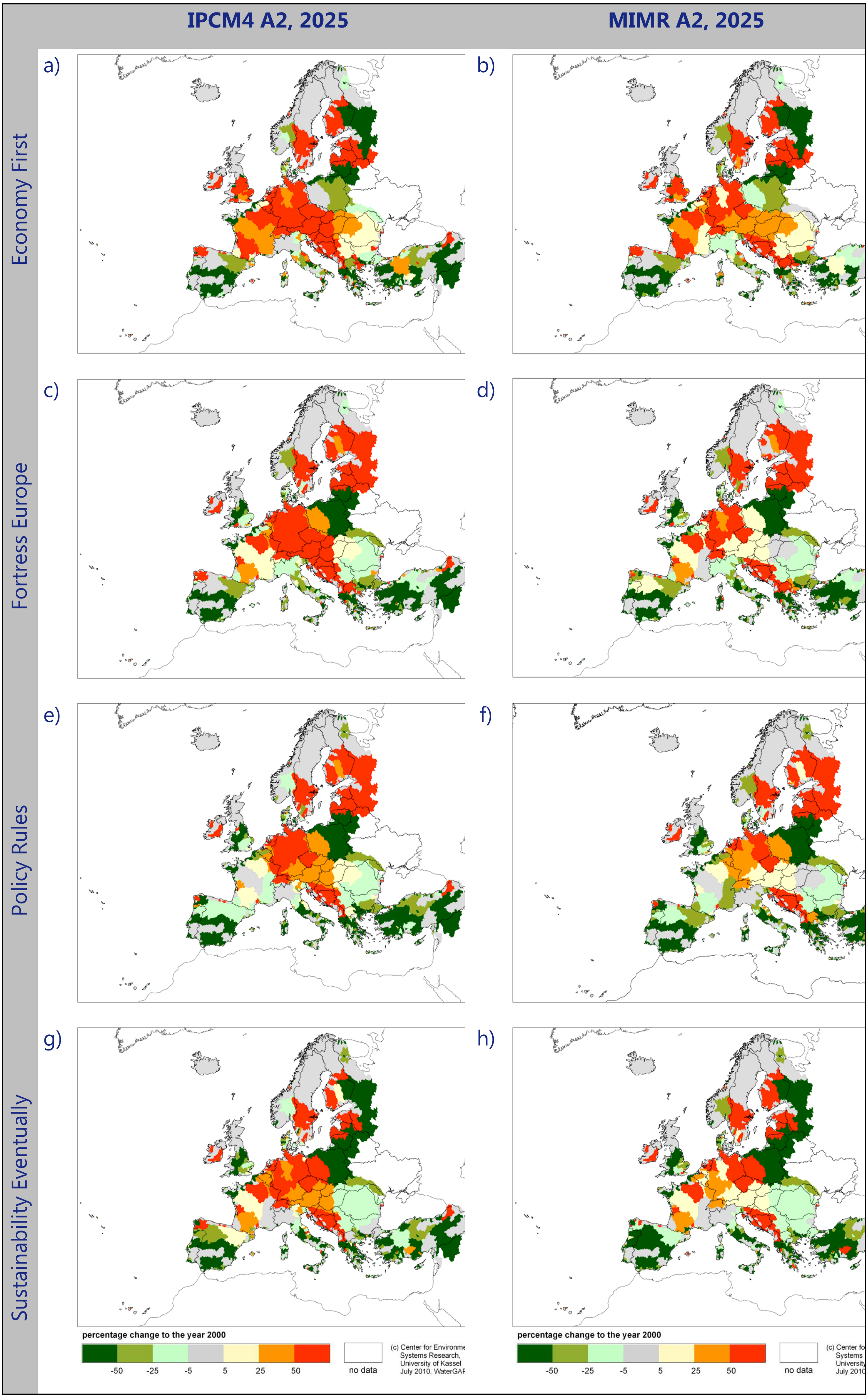

IPCM4 A2, 2025
MIMR A2, 2025
Economy First
Fortress Europe
Policy Rules
Sustainability Eventually
a)
b)
c)
d)
e)
f)
g)
h)
percentage change to the year 2000
-50
-25
-5
5
25
50
no data
percentage change to the year 2000
-50
-25
-5
5
25
50
no data

Figure 12: Change in water withdrawals for irrigation on river basin level between the base year and 2025 under two models, the IPCM4 (left) and MIMR (right) climate for four socio-economic scenarios: Economy First (a, b), Fortress Europe (c, d), Policy Rules (e, f), and Sustainability Eventually (g, h).

For water safety, the PESETA project analyzed flood risks in Europe with the LISFLOOD model, initially for the Danube and Meuse catchments (Feyen et al., 2006), to be expanded later to the European scale (materials reported in Green and White Papers, see example Figure 13). Also scenarios for droughts are emerging (Feyen et al., 2009).

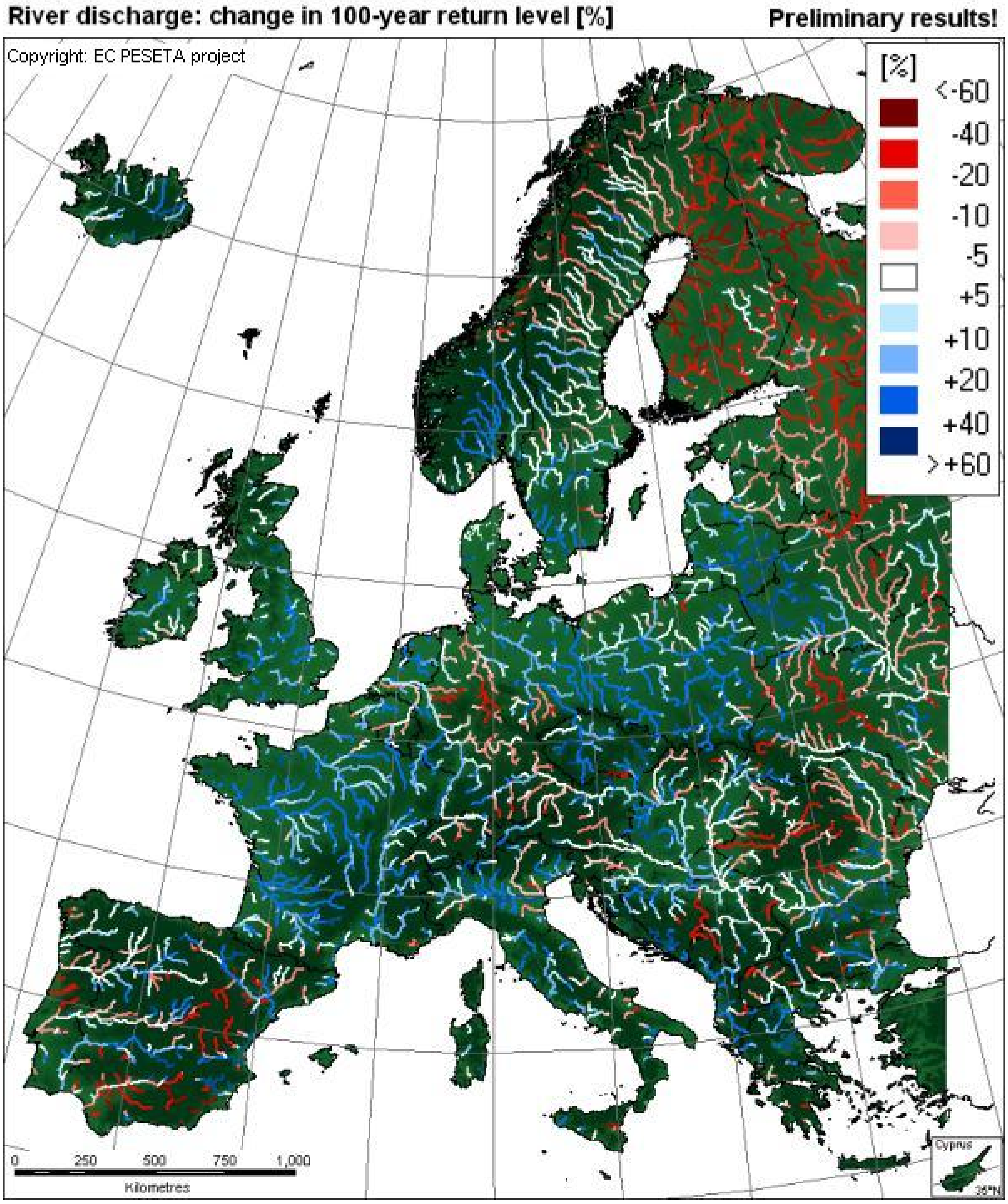


Figure 13: Relative change in the river discharge for flood events that have a probability to occur once every hundred years between the scenario run (2071-2100) and the control run (1961-1990). Simulations with LISFLOOD model driven by HIRHAM – HadAM3H / HadCM3 and IPCC SRES scenario A2. Only rivers with a catchment area of 1000 km 2 or more are shown. Map elaboration by EC JRC/IES.

5.6.2 Literature assessment on impacts

Introduction

Water is a very important cross cutting sector for the European community. Water management relates to our safety (floods, droughts and diseases) and water is a vital natural resource. Climate change will affect (water) temperature, the whole hydrological cycle including precipitation and evapotranspiration. Changes in the hydrological cycle influence the likelihood and the severity of floods and effect water depending sectors. For the coming decades floods are projected to occur more often in many European regions, particularly in winter and spring and even in regions that will become dryer on average (EEA, 2008). Water dependent sectors, such as agriculture, industries, energy, nature, infrastructure, drinking water supply, tourism and health depend on the availability of high quality fresh water. Annual river flows are projected to decrease in many parts of southern and south-eastern Europe and increase in northern and north-eastern Europe. Strong changes in seasonal run-offs are projected with lower flows in the summer and higher flows in the winter. As a consequence, droughts and water stress will increase in the summer season. The most drought prone areas are Southern and South-eastern Europe (EEA, 2008).

The availability of enough clean fresh water is crucial for the survival of humanity and is a basic requirement for sustainable development. Fresh water is used for drinking water, agriculture, industry (production process and cooling), energy production (cooling), recreation, transport and nature.

Water resources are expected to decrease in Europe as a result of increasing demand and decreasing water availability. The decrease could be in form of water scarcity, caused by high human water use or a long term decrease of water availability as a result of high temperatures and/or decreased precipitation due to climate change. Droughts on the other hand are natural phenomena and are related to natural climate variability. Climate change may cause droughts with a higher frequency, intensity and/or duration, or may change the timing of dry periods.

Climate change will also intensify the hydrological cycle, leading to more severe and/or more frequent flooding events both in the currently threatened areas (North, West, Central and Eastern Europe) and in areas currently prone to droughts such as Mediterranean (Christensen and Christensen, 2007).

European legislation

As water is a core sector, the EU has several water laws in place; the European Water Framework Directive (WFD), the Drinking water directive, the Swimming water directive and the Floods directive (FD). Water has several links with other sectoral European legislations such as the Bird and Habitat directives.

Flooding

Climate change is projected to lead to more variable river discharges. An increase in likelihood and intensity of extreme high river flows is projected for large parts of Europe due to the increase of more convective and thus extreme precipitation regimes. In general, most studies suggest that the regions currently wet, may become even wetter in future, while some dry regions such as Mediterranean and Eastern Europe will experience also more extreme precipitation events (e.g., Christensen and Christensen, 2007). Although the changes in total annual precipitation might not be that much significant, the changes in the precipitation regime might lead to longer droughts and more extreme precipitation events and thus cause shortages in fresh water supply for many sectors and increased flood damages. Extreme river flows can cause flood events, although estimates of changes in flood frequency and magnitude remain highly uncertain (EEA 2008, Dankers and Feyen 2009). Floods have a severe impact on society, causing losses both in terms of casualties, displacement of people, adverse effects on human health and the environment, and in high economic losses due to damage to infrastructure, property, agricultural land and interruption of economic activities. (EEA, 2008)

Economic and demographic development are very important drivers for flood risk e.g., Bouwer (2010) suggests that economic losses from weather related disasters (including floods) have increased due to the increased value of assets and number of people, living in hazard-prone zones. The observed increase is caused by increasing exposure and value of capital at risk. Projections from a case study from the Meuse river in the Netherlands found that anthropogenic climate change may lead to a substantial increase in potential flood losses. However, for the period up to 2040, all projections show that the contribution from increasing exposure and value of capital at risk is about 2 – 10 times larger than the contribution of anthropogenic climate change.

Within ClimWatAdapt project flood damages in Europe for 2025 and 2050 are calculated on NUTS-2 level, based on the hydrological input from LISFLOOD model and socio-economic scenarios generated within SCENES project. There is a high level of agreement between different models and scenarios on increase of water level for 100-years flood events in Northern UK and along the North Sea coast (Netherlands, and Belgium), UK, Ireland, and Norway in 2025. In the most extreme scenario most of European NUTS-2 areas are affected by more than 40%, with more than 80% of the area of some NUTS-2 units in UK, Western France, Belgium, Netherlands, Western Germany, Finland, Portugal and Spain threatened by severe floods.

The gross value added (GVA) produced and the number of people living in areas strongly affected by flood events (1-in-100-years) in 2025 is highest in UK and Ireland, Western France, Netherlands, Belgium and Italy. The most important factors, affecting the population susceptibility to flooding, are identified: those are regional units with more than 60% of their area affected by floods or regional units with high population density. In this study protection level is not taken into account in the calculations.

The severity of flood threat increases in 2050, but in general the most affected regions remain the same as in 2025. In 2050 1-in-100 year flooding event could cause severe floods in more than 80% of the area of UK, Western France, Belgium, Netherlands, western

Germany, Finland, as well as large areas in Portugal and Spain according to the upper end of projected ranges. The minimum bound of these ranges suggests that between 20% and 40% of the area of UK, Ireland, and Norway will be affected. Climate impacts determine only part of vulnerability of people to floods, however. In addition to UK, where floods will cover large parts of its territory, the highest number of people affected by severe floods will be in areas with a large population density, e.g. cities like Paris and Lyon and countries like the Netherlands.

The PESETA runs indicate increase in the water gauge of 100 year return events of river discharge in the whole of Europe as a result of climate change, with only north-eastern part of Europe as an exception. In the year 2080, between 200.000 – 450.000 additional people are affected by floods, and the damage associated with floods doubles to about 7.7 – 15 million Euro a year. Although river discharges increase in most parts of Europe as a result of climatic changes, in Northern Europe a decrease in the affected people and economic damage is projected in most scenarios. In Southern Europe less people are affected only under the most extreme scenario (5.4 °C increase of temperature).

The damage costs of European river floods and the costs for adaptation are described by the Climatecost project (Feyen and Watkiss, 2011). Using JRC's LISFLOOD model, under baseline circumstances (1961-1990) the expected annual people (EAP) flooded was estimated at 167,000 people, which has increased to more than 200,000 now. The expected annual damage (EAD, undiscounted) is calculated at 5.5 billion Euro in the baseline and 7 billion at present. Under a medium-high emission baseline (A1B scenario) with no adaptation measures taken the EAP affected would be about 300,000 by the 2050s and rise to more than 350,000 in the 2080s for climate change socio-economic change together, with about 130,000 (2050s) and more than 200,000 (2080s) due to marginal climate change impacts. The EAD in the EU27 is estimated at more than 20 billion Euro by 2020, about 46 billion Euro by the 2050s and about 98 billion Euro by the 2080s. This is a combined effect of climatic and social economic developments. The effects associated with the marginal effects of climate change alone are estimated at 9 billion Euro/y by the 2020s, about 19 billion Euro/y by the 2050s and more than 50 billion Euro a year by the 2080s. Analyses shows that damage costs can be particular high in the UK, The Netherlands, Belgium, Italy and Ireland. The numbers are highly uncertain. Runs by different models lead to variations by a factor 2 higher or lower (Feyen and Watkiss, 2011). Under an E1 stabilisation scenario, which is broadly equivalent to the EU 2 °C target, the undiscounted EAD for climate and socio-economic change taken together in the EU27 would be about 15 billion Euro by the 2020s, 42 billion Euro by the 2050s and 68 billion Euro by the 2080s. Marginal effects associated with climate change alone for the E1 scenario are calculated at more than 5 billion Euro/y by 2020, more than 20 billion Euro/y by the 2050s and more than 30 billion Euro a year by the 2080s (Feyen and Watkiss, 2011).

The Climate cost project also assessed the costs and benefits of adaptation for river flood protection. Adaptation aims at maintaining 1 in 100 year levels of flood protection across Europe. The benefits under the A1B scenario are estimated (mean ensemble, EU27, climate and social economic values, undiscounted) at €8 billion/year in 2020, €19 billion/year in 2050 and € 50 billion/year in 2080. The costs of maintaining the protection level are estimated at € 1.2 – 1.7 billion/year by 2050, € 4.7 – 7.9 billion/year by 2080 (mean ensemble, A1B scenario, undiscounted). (Feyen and Watkiss, 2011).

In terms of 100-year floods, our analysis indicates that the most vulnerable countries are Ireland, the UK, Belgium and The Netherlands. Considering the impact of climate change on floods there are large differences between different climate models.

Water scarcity

Water stress is one of the most widely-used indicators for water scarcity. It is calculated with WaterGap model (e.g., Alcamo et al., 2003, Flörke and Alcamo, 2004). In SCENES and ClimWatAdapt WaterGap is used, with input of water availability, and calculated with the LISFLOOD model. On the basis of these two parameters vulnerable spots with high water stress are identified, where water stress is determined by withdrawals-availability ratio. In both projects the same socio-economic scenarios are used: Economy first, Fortress Europe, Policy rules and Sustainability eventually.

SCENES The average annual renewable water resources available in Europe range between 1000 mm/year in the northern parts down to below 100 mm/year in regions in Spain. In general, water availability declines in the Mediterranean and in the Black See region as a result of climate change. In these regions a decrease in water availability of up to 50 percent is projected. The future precipitation distribution indicates a wetter climate in Northern and Western Europe (>25 mm/y) and a drier climate (< 25 mm/y) in the Mediterranean rim countries, especially in Spain, Southern Italy, Greece and in the Black Sea region. In the Southern and South-eastern Europe declines of water availability in the summer are projected. In these regions water shortage during the growing season is a problem because agriculture is the predominant demander. No big changes are estimated for the rest of Europe.

In 2005 the total amount of water withdrawn from freshwater reservoirs in Europe by households, factories, energy plants and agriculture was 609 km3. Most of European water resources are used for agricultural water use (mainly irrigation), followed by water used for cooling purposes in thermal power plants, domestic and manufacturing sectors. In the Mediterranean region and parts of Central Europe agriculture is the most important water user, while over larger parts of Western and Eastern Europe this is the electricity production sector and in Northern European river basins the main users are manufacturing and domestic sectors. Depending on the scenario the total water use is expected to increase (in EcF with 19 % and in FoE with 24 %) or decrease (in PoR and Sue both with 26 %). In 2050 water use decreases in three scenarios (EcF, Por and SuE) but still increases under the FoE scenario to 853 km3.

ClimWaTAdapt In the EcF scenario water stress in Europe increases on an annual basis in comparison with the base year (2005) mainly due to increased water use. There are few small exceptions to this rule - in Southern Europe there are regions where water availability is the cause of water scarcity such as Greece, Spain and Italy, and in another few regions in Italy, Greece and Bulgaria the reason is the combination of increase of water use and decrease of water availability. For the rest of Europe increased water stress is caused predominantly by increase in water consumption (withdrawals). In general, the future vulnerability to water scarcity depends more on socio-economic development than on climate change impacts, with changes in water use having greater impact on water scarcity than changes in water availability as a result of climate change.

The situation changes, when only water scarcity during the summer season is considered, however. In this case most of Europe is becoming severe water stressed, with only Central Europe and Scandinavia being exceptions. According to the projections new regions e.g., in France, Germany, the Benelux and UK will start to suffer from decreased water availability.

Regions which are currently water stressed will continue to be water stressed also in the future in this scenario.

In the Sustainability Eventually scenario severe water stress in summer is projected for more than 60% of the area in Southern Europe, even without cooling water demand. In terms of water scarcity Southern Europe is clearly the most vulnerable region in Europe (see Figure 14)

a)

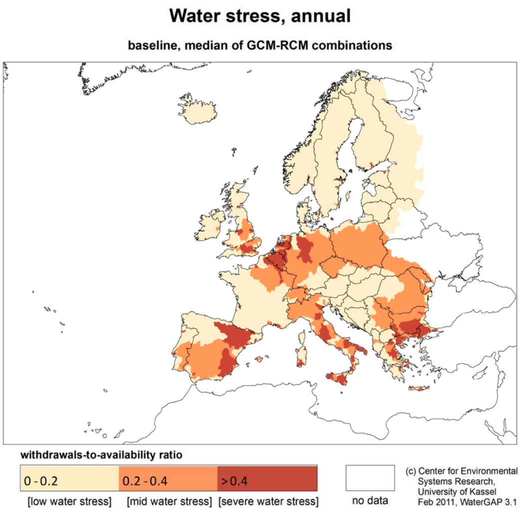
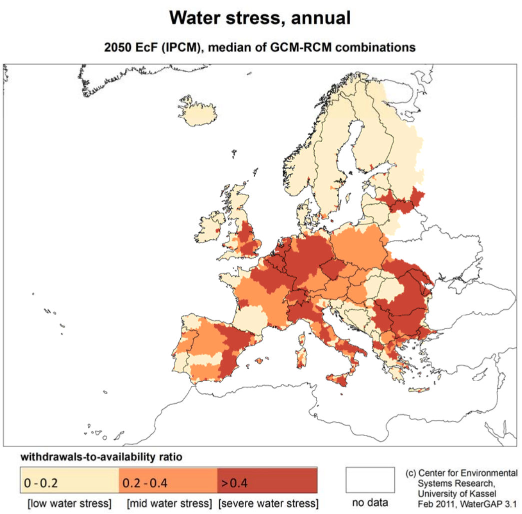
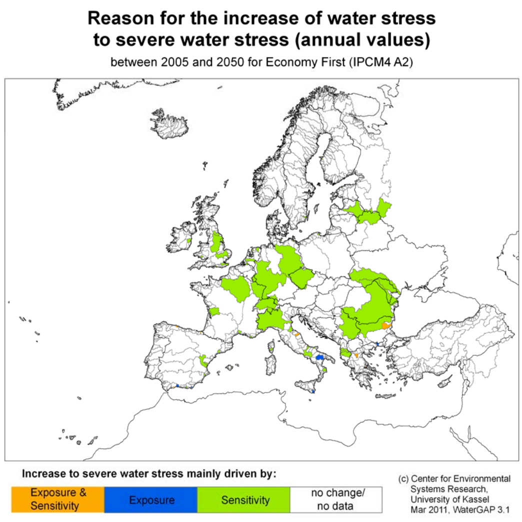


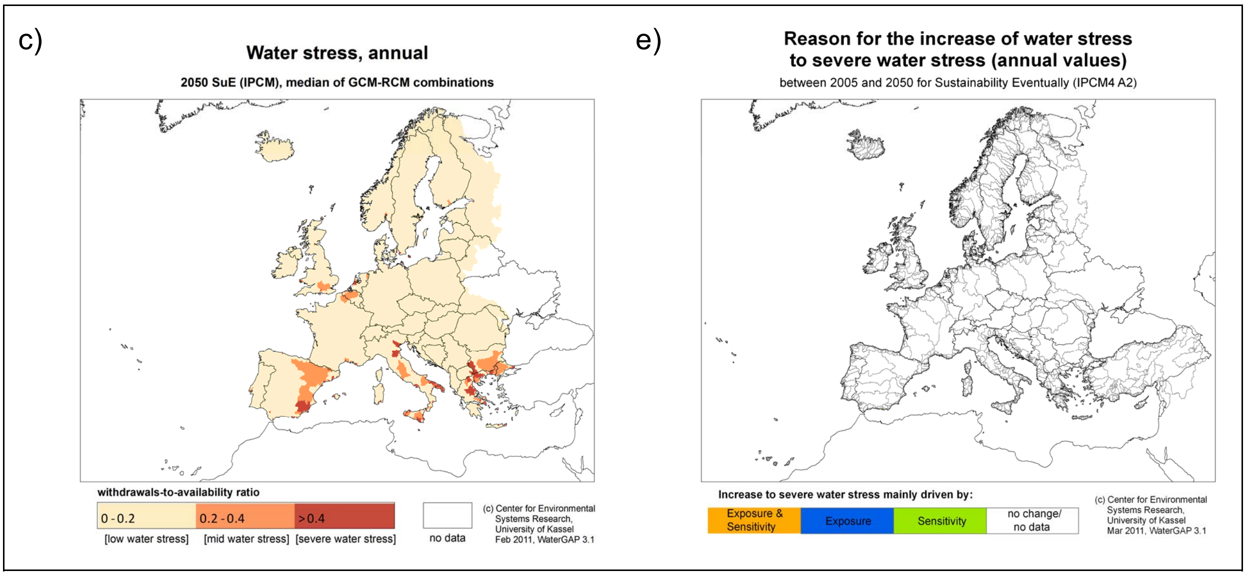
Figure 14 Annual average water stress indicator WEI on river basin level for the a) baseline, b) 2050 under EcF, and c) 2050 under SuE. The main reason of an increase in water stress from "low" or "medium" to "severe" between the baseline and 2050 is shown for d) EcF and e) SuE. Here "exposure" denotes decrease in water availability (due to changes in climate) while "sensitivity" represents changes in water withdrawals. In d) and e) no changes are shown for river basins with only minor changes in water stress or for river basins where water stress is already severe under baseline conditions, source ClimWatAdapt

b)



d)





Drought

The impact of change in the 7-day minimum flows at several recurrence intervals (10, 20 and 50 years) on NUTS-2 area and populations are the main drought indicators calculated in ClimWatAdapt. The area and population, threatened by severe droughts in the future include in the lower bound of the projections roughly the areas, suffering from water stress. In the upper bound of the projections almost the whole of Europe will be threatened by severe droughts. On average, model results indicate that drought risks will increase throughout large areas in the EU, with the exception of Northern Europe, Poland and the Baltic states. Here, a severe drought event in the 2050s is defined as a 50-years drought that is expected to occur every 10 years in the future (2050s). A 50-year drought event under baseline conditions (the drought which occurred on average once in 50 years at the end of the 20th century) will now occur more frequently, approximately every 10 years across the EU.

The CONHAZ project assessed the economic impact of droughts. The report considers the suitability of existing drought cost assessment methods for estimating costs in different economic sectors, their underlying theoretical assumptions, and application issues, such as their precision, reliability, data needs (and availability), and financial and human resources required. In addition to reviewing the methods for assessing drought costs, the report briefly examines potential policies for drought mitigation and adaptation (Logar and van den Berg, 2011).

Perez y Perez et al. (2009) estimated the direct and indirect economic impacts for the Ebro river basin in Spain. The drought of 2005 induced the loss of direct gross added value of 482 million € in the agricultural and energy production sector and indirect losses of 377 million €. The drought also caused a loss of 11.275 jobs.

Water quality

Climate change has a negative impact on water quality. If less water is in the rivers. the dilution rate for pollutants (diffuse but also waste water) will become lower causing human health problems. Higher temperatures of rivers and lakes have several effects on water quality. As a result of higher water temperature, aquatic ecosystems will move northwards and changes in life cycle events are expected. Water systems will also become more vulnerable for the dominance of harmful cyanobacteria (EEA, 2008). Higher water temperatures affect energy supply and manufacturing. Water systems will be increasingly vulnerable for release of water used for cooling, and due to higher water temperatures more cooling water will be needed. High water temperature and low water flows will result in reduction of the ability of surface waters to dilute pollutants and therefore may have severe consequences for water quality due to algal blooms, low-oxygen conditions, proliferation of thermophile pathogenic micro-organisms and increase of harmful substances. Such a decline in water quality will have a negative impact on drinking water, ecosystems and recreational water.

In addition to changes of species composition a model study on the impacts of climate change on two English rivers suggest that an increase in invasive species, diseases and parasites may threaten river ecosystems (Johnson et al. 2009) Daufresne et al. (2009) report about the observed negative effect of global warming on the body size of fish and plankton.

5.6.3 Damage and adaptation costs

Table 5.16: Damage costs Freshwater resources: floods, droughts and water quality

	2025		2080	
Sectors	**Estimated Damage Costs**	**Sources for Damage Estimates**	**Estimated Damage Costs**	**Sources for Damage Estimates**
Water management: water safety, scarcity and droughts	Medium	Mendelsohn et al 2000	Medium to High	Mendelsohn et al 2000; PESETA

Table 5.17: Adaptation costs Freshwater resources: floods, droughts and water quality

Sectors	**Themes**	**Adaptation costs (qualitative)**	**Sources**	**Notes**
Water	Floods	High (2030, 2060s, 2080s)	i.a. Bosello et al 2009, PESETA, UNFCCC 2007, Agrawala et al 2010	One of few sectors with estimates following economic cost-benefit calculus, but still with a wide uncertainty range partly due to uncertain sea level rise
	Water resources/water scarcity	Medium (2030, 2060s, up to 2080)	Fischer et al 2007, Bosello et al 2009, UNFCCC 2007, Agrawala et al 2010	
	Droughts			
	Water quality	Uncertain		Very low coverage

5.6.4 Summary

Summarizing main problems

With more drastic changes in climate towards the end of the 21st century, serious climate change impacts on water quantity and quality are expected in most European regions. Extreme precipitation events may lead to high river flows, leading to flooding, loss of lives and economic damage. The risks of flooding are increasing due to increasing human populations and economic investments.

The Mediterranean and eastern European regions will be the most vulnerable to water scarcity and drought due to climate change, while large part of Europe might suffer from water stress due to increase in water use. This trend is especially significant in scenarios of the type “Economy first”, while in sustainable scenarios water stress decreases comparing with the base year.

At some areas annual average numbers mask increase of extremes, e.g., increase above the base line winter precipitation and decrease of spring/summer precipitation. When only summer water availability is considered, the areas affected increase considerably.

Knowledge gaps

The main knowledge gaps in the area of water resource vulnerability are Economic consequences of future flooding, water scarcity and drought; intersectoral linkages increasing vulnerability; and future changes in water quality and their effect on water quantity and ecology . They need to be filled as pre-requisite for effective adaptation planning,

Table 5.18: Summary table Freshwater resources: floods, droughts and water quality

Climatic driver or social economic drive	Sub-threat or *opportunity*	Time-frame	Area affected[1]	Potential environmental impacts[3]	Potential economic impacts[3]	Potential social impacts[3]	Level of agreement and evidence	Reference
Precipitation, cryosphere changes	Floods	1996	Unevenly distributed though EU. The British islands and Central, East and south Europe are the most vulnerable	n.a.		194.000 people in EU affected		PESETA Current situation
		2080		n.a.	7,728 Additional expected damage (million/y)	276.000 additional people in EU affected		PESETA: 2.5° B2HadAM3h
		2080		n.a.	11,469 Additional expected damage (million/y)	318.000 additional people in EU affected		PESETA: 3.9° A2HadAM3h
		2080		n.a.	8,852 Additional expected damage (million/y)	251.000 additional people in EU affected		PESETA: 4.1° B2ECHAM4
		2080		n.a	15,032 Additional expected damage (million/y)	396.000 additional people in EU affected		PESETA: 5.4° A2ECHAM4
Precipitation	Floods (1-in_100y flood	2025	40% more areas in most of Europe and more than 80% of NUTs-2 areas in UK, Western France, Belgium, Netherlands, western Germany, Finland, Portugal and Spain will be flooded	n.a.	Gross value added (GVA) produced (all ClimWatAdapt results will be available in June)		high	ClimWatAdapt, Economy first
	Floods (1-in_100y flood	2050	Lower bound of projections: 20% to 40% of the area of UK, Ireland, and Norway Upper bound of projections: severe floods in more than 80% of the area of UK, Western France,	n.a.			high	ClimWatAdapt, Economy

Climatic driver or social economic drive	Sub-threat or *opportunity*	Time-frame	Area affected[1]	Potential environmental impacts[3]	Potential economic impacts[3]	Potential social impacts[3]	Level of agreement and evidence	Reference
			Belgium					
Precipitation	Floods	Baseline (1961-1990)	EU27		**5.5 billion AED**	**167,000 EAP**	Low	Feyen and watkiss , 2011
	Floods	2020 (A1B)	EU27		**20 billion EAD** **Climate change alone:** **9 billion EAD**		Low	Feyen and watkiss , 2011
	Floods	2050 (A1B)	EU27		**46 billion EAD** **Climate change alone:** **19 billion EAD**	**300,000 EAP**	Low	Feyen and watkiss , 2011
	Floods	2080 (A1B)	EU27		**98 billion EAD** **Climate change alone:** **50 billion EAD**	**360,000 EAP**	Low	Feyen and watkiss , 2011
	Floods	2020 (E)	EU27		**15 billion EAD** **Climate change alone:** **5 billion EAD**		Low	Feyen and watkiss , 2011
	Floods	2050 (E)	EU27		**42 billion EAD** **Climate change alone:** **20 billion EAD**	**300,000 EAP**	Low	Feyen and watkiss , 2011

Climatic driver or social economic drive	Sub-threat or *opportunity*	Time-frame	Area affected[1]	Potential environmental impacts[3]	Potential economic impacts[3]	Potential social impacts[3]	Level of agreement and evidence	Reference
	Floods	2080 (E)	EU27		**68 billion EAD** **Climate change alone:** **30 billion EAD**	**360,000 EAP**	Low	Feyen and watkiss , 2011
Water use (withdrawals)	Water scarcity	2005			609 km^3		high	SCENES
		2025 – 2050			+ 19%			SCENES, EcF
		2025 – 2050			+ 24% + 40 %			SCENES, FoE
		2025 – 2050			- 26 %			SCENES, PoR
		2025 – 2050			-26 % -62 %			SCENES, SuE
Water use	Water scarcity, annual	2050	Western and eastern Europe		Almost double increase in Western and Eastern Europe		medium	ClimWatAdap, EcF
	Water scarcity, annual	2050	Western and eastern Europe		About four time decrease in West Europe, three times in East and North and two times in South		medium	ClimWatAdap, SuE

Climatic driver or social economic drive	Sub-threat or *opportunity*	Time-frame	Area affected[1]	Potential environmental impacts[3]	Potential economic impacts[3]	Potential social impacts[3]	Level of agreement and evidence	Reference
	Water scarcity, annual	2050	West and east Europe		About 60 % increase in Western, Eastern and North Europe, slight decrease in Southern Europe,		medium	ClimWatAdap, EcF
	Water scarcity, annual	2050	Southern and western Europe		Almost 3 times decrease in Southern and Western Europe		medium	ClimWatAdap, SuE
Water availability	Water scarcity	2005	Mediterranean, Eastern Europe		100 – 1000 mm			SCENES
	Water scarcity		Mediterranean, Eastern Europe		- 50%		high	SCENES
	Water scarcity, annual	2050	Southern Europe		No significan changes in averages, about 11 % decrease in Sothern Europe		high	ClimWatAdap
	Water scarcity, summer	2050	Most of Europe		Average decrease of about 13 %		high	ClimWatAdap
Water availability	Drought	2005	Ebro river Span		Direct costs: 482 million Euro Indirect costs: 377 million €	Loss of 11,275 jobs	High	Perez y perez et al. 2009
WaterStress	Water scarcity, annual	205o	Southern Europe most affected		10% of Europe		high	ClimWatAdapt, baseline

Climatic driver or social economic drive	Sub-threat or *opportunity*	Time-frame	Area affected[1]	Potential environmental impacts[3]	Potential economic impacts[3]	Potential social impacts[3]	Level of agreement and evidence	Reference
	Water scarcity, annual	2050	Southern Europe most affected		25% of Europe		high	ClimWatAdapt, EcF
	Water scarcity, annual	2050	Southern Europe most affected		5% of Europe		high	ClimWatAdapt,, SuE
	Water scarcity, summer		Southern Europe most affected		Slight decrease in affected area in Southern and Western Europe, large (>40 %) decrease in affected area Eastern Europe		high	ClimWatAdapt,, SuE
	Water scarcity, summer	2050	Southern, West Europe most affected		25 % more water stressed area in Souter Europe, 3 times increase of water stress area in Western Europe		high	ClimWatAdapt,, EcF E

5.7 Energy

5.7.1 Scenarios

A large number of scenario studies exist for the energy future of the European Union, mostly in the context of European energy and climate mitigation policy development, such as analysis to support the EU targets for greenhouse gas emissions reductions and long-term commitments consistent with the target to restrict the global temperature increase to 2 degrees Celsius. The European Commission commissioned a study to analysis and compare relevant mid- and long-term energy scenarios for EU and their key underlying assumptions. Rademaekers et al, (2010) identified 5 European/governmental studies, 10 scenario studies by international or non-governmental organizations, and 10 studies from the private sector (Prognos, 2010, report available May 2011, see also http://ec.europa.eu/energy/nuclear/forum/opportunities/competitiveness_en.htm). These studies generally include transport but do not take into account the impacts of climate change on energy use (less heating, more cooling), or the vulnerability of the future energy system for climate change impacts. Some studies (the WITCH model of FEEM (analyzed in the PLANETS study) take into account climate effects endogenously (not specifically heating/cooling demand, but overall damage for the economy modeled; Rits, 2011).

Since about half of power grid system faults are caused by weather effects (Toth, 2010), it would be important to spend more attention to this issue, e.g. the vulnerability of hydropower and biofuels for changes in precipitation and temperature, of thermal power generation for impacts on cooling water, of power infrastructure for increased frequency and intensity of extreme events, of pipelines for melting permafrost (e.g. see Paskal, 2009). Various methods to assess the vulnerability of energy systems have been developed and applied, but usually in the context of developing countries. No Europe-wide scenario analysis of the vulnerability of the energy has been identified, but the methods available for developing countries (e.g., see Williamsen et al., 2009) could be adapted to be applied in a European context.

5.7.2 Literature assessment on impacts

Introduction

In Europe, the vulnerability of the various components of the energy system has received very little attention, with energy policies focusing on competitiveness, security of supply and greenhouse gas mitigation. Climate policy may have been so strongly associated with CO2 reduction that adaptation policy was overlooked. At the national level, especially Scandinavian countries have assessed the vulnerability of the energy system (e.g. for Finland, see Ministry of Agriculture and Forestry (2005); for Sweden, see Ministry of the Environment (2007), and http://www.defra.gov.uk/environment/climate/sectors/reporting-authorities/ for the UK). None of the many scenarios that have played a role in the EU policy discussion actually pays any attention to the systems vulnerability, or to adaptation options to reduce vulnerability. Some general scenario studies refer to cooling water availability (Energy Technology Perspectives, 2010), or mention that they do not take into account changing cooling/heating demand but rather keep degree days constant at a certain level (e.g. year 2000 in the EU DG TREN study of 2009; Rits, 2011).

In the power sector, reacting to the Adaptation Green Paper, Eurelectric (2007) has proposed to maintain or improve energy security through diversification of energy sources and operational flexibility of individual power plants. Eurelectric recommends research to evaluate the climate resilience of new sites for power plants, of existing procedures for emergency situations, and of new, renewable energy sources. Eurelectric also stresses the relevance of energy scenarios that take into account climate impacts on demand and supply. Environmental impact assessment of energy installations almost invariably assesses how the installation may change the environment, but not how the environment might affect the construction and operation over the lifetime of the project (Paskal, 2010). Nevertheless, various components of the system are vulnerable (e.g., see Swart and Biesbroek, 2008; Paskal, 2010; Rademaekers et al., 2010). The following vulnerable energy system components can be distinguished:

- Energy demand
- Renewable energy (hydropower, biofuels);
- Thermal facilities (nuclear, fossil-fired, geo-thermal, waste incineration);
- Offshore or coastal production and facilities;
- Energy infrastructure in cold climates, resting on melting permafrost.

European legislation

So far, European energy policy has not taken into account the vulnerability of the energy system to climate change. For example the Biofuels Directive (EC, 2003), the Biomass Action Plan (EC, 2005) or the European Energy Strategy (EC, 2010) do not refer to the vulnerability of biomass and water energy to climate change. Nevertheless, climate change can affect the likelihood of achieving the ambitions of the EU for greenhouse gas emissions reductions and it can change the vulnerability of the energy infrastructure. Also, energy security may be affected through impacts elsewhere, e.g., through damages to production and transmission facilities. Many large-scale energy facilities may have to undergo a Strategic Environmental Assessment (SEA) that could take potential climate change impacts and climate resilience into account, but limited methods and tools on how to do this are yet available (OECD-DAC SEA TF: Guidance note – SEA and adaptation to climate change (2008))(Strategic Environmental Assessment and climate change: Guidance for practitioners (2007)).

As to power networks, European policy attention does not consider vulnerability yet. The Guidelines for trans-European energy networks (EC, 2006, revising earlier 2003 guidelines). TEN-E's main aims are the effective operation of the internal energy market, the security and diversification of supply, strengthening territorial cohesion in the European Union, and finally sustainable development, in particular by improving the links between renewable energy production and more efficient technologies. The Guidelines list and rank projects eligible for Community assistance, and mention the importance of environmental impact assessment of projects, plans and programmes, but they do not yet address a decrease of vulnerability to climate change or increase of resilience. At the same time, it should be noted that a stakeholder consultation suggests that 100 % of the nuclear power facilities and half of the fossil-fuel plants in Europe, but less than 5 % of renewable plants and distribution networks have performed a climate change effect assessment (Rademaeker et al., 2010). About half of those stakeholders who did an assessment also included these effects in their long-term strategies.

Energy demand

The changing climate is likely to lead to some changes in energy demand. Three effects are important:

- The demand for heat goes down, while the demand for cooling goes up (EEA, 2008).
- In some places, peak demand may shift from winter to summer.
- The regional distribution of demand will change.

A UK study specifically addressing the heating/cooling issue suggests that the fall in heating energy demand is approximately equal to the rise in cooling demand as a result of climate change up to the 2080s in the UK over the year (Chow and Levermore, 2010). Similarly, Aebischer et al. (2007) find that for much of Europe, increases in cooling energy demand due to global warming would be outweighed by reductions in the need for heating energy. This is less optimistic than the global study by Tol (2002a, b), reported in the IPCC AR4, which suggests that at the global level benefits by decreased heating demand would be larger than increased cooling requirements.

Global warming leads to a decrease of energy demand for heating. A 2ºC warming by 2050 in the United Kingdom is expected to lead to a decrease by 5%-10% fossil fuel demand and 1%-3% electricity demand. On the short term (2021-2050) the heating demand in Finland may be decreased by 10%, around 2100 by 20%-30% (Kirkinen et al, 2005). In Hungary and Romania the winter heating demand (2021-2050) decrease by 6-8 per cent. In the Mediterranean 2 to 3 fewer weeks a year will require heating by 2050. The savings in 2050 of oil and natural gas fuels are for Finland 0.35% of the GDP, for Germany 0.07% (coal) and 0.05 (oil and natural fuels) of the GDP (Pilli-Sihvola et al., 2010).

Alcamo et al. (2007) gave an overview of the changes in energy demand in Europe: In the Mediterranean a decrease in energy heating requirements of 10% and increase of 30% in cooling requirements is expected by 2030 (Cartalis et al, 2001). In 2080 the electricity demand in Italy and Spain is expected to increase by 50 percent for summer space cooling by air conditioning. In Athens a 30% increase is expected (Giannakopoulos, 2006). Peaks in electricity demand are likely to equal or exceed peaks in demand during cold winter periods in Spain (Lopez Zafra et al, 2005). Also in Northern Europe an increase in electricity demand for cooling is expected. According to LCCP (2002) the increased energy demand in London by 2050 is 10% and 20% around 2080. The costs for cooling in Spain are expected to rise with 0.22 (oil) and 0.16 (natural gas) of the GDP by 2050 (Pilli-Sihvola et al., 2010) In Greece the electricity demand by 2071 – 2100 will increase by 2.6 to 5.5 percent under A2 and B2 emission scenario’s. This may lead to an additional expenditure for electricity generation of 170 -770 million Euros by the end of the 21th century (Mirasgedis et al., 2007).

Under a 4°C scenario average until 2100 and very moderate climate policies up to 2050 an increase of the electricity demand by roughly 1.7% by 2050 compared to the base line scenario. The ADAM study estimates that the increase in cooling demand causes an extra investments in air conditioning and cooling systems of 8.4 billion Euros. The additional electricity generation costs 7.3 billion Euros until 2050 (Jochem et al., 2009). The changes in energy declines in a 4 °C temperature rise scenario by 2050. The total cost savings are estimated about 27.5 billion Euro in the EU27+Norway and Switzerland (Jochem et al. 2009).

Tol (2002) performed estimations for the damage costs of changes in Energy demand. He based his calculations on a study by (Downing et al. (1995, 1996). He estimated that a 1 °C global temperature rise leads to a saving of 13.1 billion USD a year on heating demand for OECD-Europe and 46.0 billion USD for Central Europe and the former Soviet Union. The additional costs for cooling are estimated at 20.2 billion USD/year for OECD-Europe and 18.6 billion USD/year for Central Europe and the former Soviet Union.

Renewable energy

Renewable energy technologies are very heterogeneous and the impact from climate change differs between the different technologies.

Hydropower is one of the most important sources of renewable energies in Europe. According to Rademaekers et al, (2010) the potential for hydropower in Northern Europe will increase as a result of increased runoff and river discharge. The potential is likely to be increased by 25 per cent in 2050 up to 30 per cent in 2070. However in Southern Europe the impacts are negative. The potential for hydropower is likely to decrease by 25 per cent in 2050 and up to 50 per cent in 2070. Other studies also find decreases in low water flows for Southern and Central Europe. An outcome of the SCENES project is that in general, water availability declines in the Mediterranean and in the Black See region as a result of climate change. Hydropower facilities such as dams, turbines and reservoirs are generally designed on the assumption that the climate (e.g., precipitation) and the resulting run-off vary within predictable ranges, but climate change is projected to alter those ranges. Particularly installations at rivers and streams determined by glacial run-off regimes are vulnerable. Drier summers and wetter winters will change the distribution of water availability over the year, possibly affecting power generation at the different scales (e.g. small hydro-power facilities at upstream streams are benefitting already from glacial retreat and will further do while hydro-power stations at nival-pluvial regimes do not) and causing erosion. Both periods with high and low precipitation can affect dam operations and have impacts not only on power production, but also on the reliability of water availability for drinking water, industrial use or irrigation.

We assume the impact of climate change on biofuel production is similar to the impact on plant production (see impact assessment on agriculture). Although closely related to the vulnerabilities of agricultural production, the vulnerability of biofuel production to climate change has only recently been recognized. This has primarily been done in the context of developing countries (e.g. for Brazil, see Frossard Pereira de Lucena et al., 2009; for Africa, see Williamson, 2009). The impact can be negative because of damage from extreme events and drought periods, but positive in cases where increased CO2 levels and suitable temperature and precipitation conditions may increase potential yields, at least for a modest amount of temperature change. For electricity / heat generation from biomass the temperature affects the efficiency of the process and availability of cooling water. A flooding would also affect biomass production.

Since wind patterns may change as a result of climate change, also wind energy potential may change.. More studies project an increase of wind speeds over Europe. Pryor et al. (2005) projected increased wind energy densities over large parts of Northern Europe, particularly over wintertime. Nevertheless, Rademaeker et al (2010) suggest that plans for new wind farms may want to take into account increased wind speeds, in addition to sea level rise for offshore installations. Because wind turbines have a relatively short lifetime of about 10-15 years, the climatic changes over such a period are likely to be small, and new conditions can be taken into account when replacing or repowering a wind park.

According to Williamson (2009), the efficiency of photovoltaic power generation (solar power) decreases as ambient temperatures rises, and hence increase in temperature results in a decrease in electricity production. This could lead by a 2°C increase of temperature to a decrease of 1 % in efficiency of solar cells in the Mediterranean. In Scandinavia the yield could drop with 6 per cent as a result of reduced reflection due to less snow cover and changes in solar irradiation. The absence of cooling water is the main problem for concentrating solar power (CSP). This problem can be more severe than for convential thermal technologies, as CSP plants are usually suited in areas already suffering from water shortages. While solar power facilities may be damaged by increased frequency and intensity of storms during unpredictable occurrences. Changes in the cloudiness may have a more significant effect (Rademaekers et al., 2010).

Rademaekers et al. (2011) performed a cost impact study on different energy producing sectors. For hydropower the cost assessment of climate impact in 2080 are estimated roughly at € 4.8 billion/year for wind on land roughly at € 0.4 billion, for wind offshore roughly at € 13.1 billion/year, for biomass production € 1.8 billion/year and for PV roughly € 0.1 billion/year (Rademaekers et al, 2011).

Thermal power plants

Thermal power plants produced up to 85% of the electricity within the EU27 countries (53% fossil, 28% nuclear and 4% biomass). Thermal generation technologies can be considered as a homogeneous group when the impacts of climate change are concerned. They all need to be protected from flooding and need cooling (Rademaekers et al, 2011). Thermal power plants (nuclear, fossil-fired, geo-thermal, waste incineration) require a reliable supply of cooling water, both in terms of quantity and quality, e.g. increased water temperatures and decreased runoffs may constrain that availability. Because these plants need cooling water they are often sited along rivers or coasts, making them vulnerable to flooding. A 1 °C temperature rise in river temperature may decrease the power output by 0.12% (Durmayaz and Sogut, 2006). Paskal (2011) reports that during the 2003 heat wave, a kind of heat wave which is projected to be common by the middle of the century, 17 French nuclear plants had to be powered down or shut off, costing the utility about 300M€ due to the need to buy alternative, more expensive electricity. Förster and Lilliestam (2009) estimate the economic impact of heat waves for a typical German nuclear power plant, given different temperature and runoff scenarios. According to a scenario of 2 degrees warming and 50 % runoff decrease, the annual production is reduced by 8%. This may lead to an average income loss of 80 million € and a potential loss of 111 million € in the worse case scenario.

The withdrawal of river water and the discharge of cooling water back into the river is regulated by threshold values. In the Netherlands, for example, water from the river Rhine cannot be used for cooling once its temperature would rise over 28ºC after leaving the cooling installations, because that would be too much of a threat to the water quality (www.helpdeskwater.nl). These threshold values could be reached more frequently in the future, as ambient temperatures as well as heat periods and droughts might increase due to climate change (Greis, 2010). The long lifetime of power plants makes it essential to take climate change threats into account when designing and locating the plants.

Rademaekers et al. (2011) performed a cost impact study on different energy producing sectors. For nuclear power the cost assessment of climate impact in 2080 are estimated roughly at € 5.5 billion/year, for natural gas roughly at € 5.7 billion/year, for coal roughly at € 5.7 billion/year, for oil roughly € 0.5 billion/year. For the grid infrastructure the damage costs are estimated roughly at € 13.2 billion/year (Rademaekers et al, 2011). Planning for new generation technologies in Member States should take possible impacts of climate change and avoid unexpected disruption of generation into account. The expected lifetime of a power plant is also an important aspect to consider. For renewable energy plant operators the unit adaptation costs (= climate adaptation costs per installation in Euro) are about three times higher than for nuclear energy and over two time higher than for fossil fuel fired power plants (Rademaekers et al. 2011).

Offshore and coastal production facilities

Coastal production or refining facilities can be subject to flooding by sea level rise and increased exposure to wind storms and storm surges. Offshore facilities (oil rigs, wind farms) are exposed to strong winds. However, according to expert statement the structures are designed for enduring rough weather conditions and therefore should withstand climate change impacts. Scientific studies on this topic are still lacking.

Installations in the Arctic

Although the European arctic is relatively small and sparsely populated, energy facilities (pipelines, power lines, switch stations, etc.) located there may, on the one hand, subside due to melting permafrost (ACIA, 2004). On the other hand, new fuel resources may become accessible, noting that the environmental risks of energy production in the harsh and ecologically sensitive Arctic is also posing major risks to local ecosystems and communities.

The same problems may occur for small hydropower stations and related dam constructions in high alpine environment.

Transmission and distribution networks

Climate change effects transmission and distribution facilities in four ways: through wind and storms, temperature, droughts and flooding. Networks are vulnerable for increasing frequencies of storms and heavy winds. Storms and heavy winds can lead to serious damages:

- In 2005 a power failure in a German electricity grid caused at least 10 million euro in damages from snow storms and blackouts for about 250,000 people in western Germany. Storms and snow toppled pylons and iced power lines in North Rhine-Westphalia. Damage cost estimates range from €1,600 per fault for a single line breakage (Martikainen et al, 2007) to €17,000 per pylon and attached lines in cases of widespread disruption (ADAM, 2009). RWE Netz had to re-enforce 28,000 pylons of its transmission grid following icy winter storms in 2005. This cost the company €500 million;
- France suffered severe storms in January 1999, with gusts of up to 200 km per hour, during which 3.5 million customers lost power. The resulting costs to EdF were €1.1 billion (Peters et al, 2006);

- In the Netherlands, five pylons of Tennet's transmission grid were blown over in a thunder storm in July 2010. The pylons were installed in 1971, and should have lasted 50 to 100 years. Since then, Tennet s engaged in a comprehensive analysis of the potential impacts of climate change on electricity transmission. (Rademaekers et al, 2011)
- Also in 2003, 55 million people in Italy were affected when supplies from France and Switzerland were interrupted allegedly because of storm damage.

Strengthening networks to prevent storm damage is already considered by several Energy companies. In France the RTE is working on 45000 km overhead lines in a 2.4 billion Euro program (Rademaekers et al, 2011).

Increasing wind speeds can also have a minor positive effect. Wind cools down the overhead lines and an increase of wind speed can improve the capacity of the lines.

Heat can also pose risks. The maximum operating temperature for a network is 80°C at the conductor surface. If this is exceeded, overheating can damage the systems and poses a fire hazard and the capacity of the network goes down (Rademaekers et al., 2011). E.g., on a hot day in 2003, an estimated 10 million people in Ontario and 45 million people in eight U.S. states were affected by a blackout when power lines were overloaded and overheated when people turned on cooling equipment. A more gradual impact is the fact that network capacity declines with rising temperature, as the resistance of metals increases and the systems sooner reach their maximum operating temperature (Rademaekers et al., 2010). These examples demonstrate that potential climate impacts can affect the trans-European networks plans for power (TEN-E). For example, problems in one country can affect the power supply in other countries. In 2009, the European Union has adopted the third regulative package to increase cross-border exchanges in electricity, which has to be implemented by member states in 18 months (http://ec.europa.eu/energy/gas_electricity/legislation/legislation_en.htm). This may increase international interdependencies.

A more intensive hydrologic cycle may lead to increased risk of hydropower infrastructure and safety of reservoir dams. Although hydropower plants are the most jeopardized structures in the total electricity supply system (Hauenstein, 2005), on the other hand hydropower infrastructure is designed to withstand floods (Held et al, 2010).

Geo-political factors

Vulnerability of energy production in other parts of the world (e.g., offshore oil and gas platforms to hurricanes, key oil and gas distribution pipelines to landslides or melting permafrost) can affect global energy security and energy prices.

Socio-economic developments affecting exposure, sensitivity and adaptive capacity

If climate change poses particular threats to the energy system, this not only depends on the potential impacts, but also on socio-economic developments that affect exposure, sensitivity and adaptive capacity to climate change. For example, the increased reliance on electricity and renewable energy may increase the vulnerability of Europe's energy system to climate change, even if it would decrease its vulnerability to non-climate factors such as dependence on fuel imports from unstable regions. Policies can be put in place to reduce or avoid this increased dependence, but these have not yet been considered.

Energy demand also depends on the size of the human population in Europe. Currently, a decline is expected with a birth rate of 1.6 children per woman in the EU whereas the population replacement level is 2.1 (http://europa.eu/legislation_summaries/employment_and_social_policy/situation_in_europe/c10160_en.htm). A decline in the population may be prevented by immigration.

5.7.3 Damage and adaptation costs

Table 5.19: Damage costs Energy

	2025		2080	
Sectors	**Estimated Damage Costs**	**Sources for Damage Estimates**	**Estimated Damage Costs**	**Sources for Damage Estimates**
Energy	Energy demand: overall negative, but with variation in winter/summer, regional and type of energy carrier	Tol 2002a	Demand: Negative; Supply: Low to Medium	Bosello et al 2009; Tol 2002; ADAM

Table 5.20: Adaptation costs Energy

Sectors	**Themes**	**Adaptation costs (qualitative)**	**Sources**	**Notes**
Energy	Renewable energy	Medium (no indication of time frame)		Change of location of renewable power plants, costs not assessed in literature Costs will be diverse for different types of renewable energy
	Thermal facilities	High (up to 2060s)	Jochem and Schade 2009, Bosello et al 2009	
	Offshore and coastal production	Low (no indication of time frame)		According to expert statements (personal communication), structures are sufficiently weather-proof to withstand climate impacts
	Energy distribution infrastructure	High (2010-2050, 2060s)	World Bank 2009, Bosello et al 2009	Climate proofing of infrastructure
	Energy security	High (up to 2060s)		See "Thermal facilities"

5.7.4 Summary

Summarizing main problems

Energy production facilities that depend on the cooling function of rivers are doubly vulnerable: during a drought there is less water in rivers and their water temperature may be higher. For nuclear power plants this may necessitate expensive shutdown events. Low water flows also affect hydropower. Installations along the coast may be affected by flooding, however, they are possibly already built to withstand such effects.

Knowledge gaps

Vulnerability of energy systems has received little attention; most attention has been on mitigation of climate change.

About the climate impact on coastal infrastructure and offshore some effects are known, but knowledge is lacking how these will change in the future.

Table 5.21: Summary table Energy

Climatic driver or social economic driver	Sub-threat	Time-frame	Area affected[1]	Potential environmental impacts[3]	Potential economic impacts[3]	Potential social impacts[3]	Level of agreement and evidence[2]	References
Changing precipitation patterns and temperature increase	Potential and average changes in income for Nuclear plant in Germany	1 - 5 °C river temperature rise and decrease of stream flow 10 -50%	Nuclear plant Germany	NA	Average 80 million Euro/year Potential 110 million Euro a year	NA	Low	Foster and Lillestam 2009
Changing precipitation patterns	Different potential for hydropower due to different average debit of rivers	2050	Northern and Southern Europe	NA	Northern Europe Increased potential by 25% in 2050 up to 30% in 2070 and an decreased potential in Southern Europe of 25% in 2050 up to 50% in 2070	NA	Low/medium	
	Unpredictable hydropower potential due to more extreme weather patterns	2020	Mountain areas	NA	High costs for alternative supplies; reduced security of supply; reduced efficiency/capacity Up to 14.8 10^9 €	Lack of drinking water Flooding Lack of water for irrigation	High agreement, medium evidence	
	Affected yield renewable energy (biofuels)	2080	Agricultural areas across Europe	NA		Affected employment in agriculture sector	Low agreement, medium evidence	Rademaekers et al., 2010[1,] Frossard Pereira de Lucena et al, 2009
Temperature increases	Changing energy demands for cooling and heating	2020	All Europe; a decrease in energy demand for heating and an increase in energy demand for cooling	NA	Decreased energy demand for heating: Mediterranean (2030) 10%-30%; Northern Europe (UK and FIN) (2035) 5%-10% and (2100 FIN only) 20%-30%	NA	High/high	Cartalis et al, 2001, Alcamo et al, 2007, Giannakopoulos (2006), Lopez Zafra et al, 2005, LCCP (2002), Kirkiner et al 2005

Climatic driver or social economic driver	Sub-threat	Time-frame	Area affected[1]	Potential environmental impacts[3]	Potential economic impacts[3]	Potential social impacts[3]	Level of agreement and evidence[2]	References
					Central and East EU (2035 ROE and HUN) 6%-8% Increased energy demand for cooling Southern EU 2080 (IT and SP) 50% Northern EU (Londen, 2050) 10%-20%			
Temperature increase	Changes in electricity demand for cooling and investment in cooling equipment	2050	EU 27	NA	Investment 8.4 billion € Generation 7.3 billion € per year	Increase in electricity demand by 17% Northern EU (-0.5%) Western EU (+0.5%) Central east EU (+0.7%) Southern EU (+4.9%)	Low	Jochem et al. (2009)
Temperature increase	Changes in energy demand	2040	EU 27 + Norway and Swiss	NA	Energy saving 27.5 billion Euro		Low	Jochem et al. 2009
Temperature increase	Changes in energy demand	2080	Greece	NA	Additional cooling demand 170 -770 million a year		Low	Mirasgedis et al. 2007
Temperature increase	Changes in energy consumption	2050	Finland, Germany and Spain	NA	Finland (- 0.35%GDP) Germany (- 0.07%GDP (coal) - 0.05%GDP (oil and gas)) Spain (0.22%GDP		Low	Pilli-Sihvola et al., (2010)

Climatic driver or social economic driver	Sub-threat	Time-frame	Area affected[1]	Potential environmental impacts[3]	Potential economic impacts[3]	Potential social impacts[3]	Level of agreement and evidence[2]	References
					0.16%GDP (gas))``			
Temperature increase	Changes in energy demand for cooling	1 °C temperature rise	OECD Europe Central and Eastern Europe and the former Soviet Union	NA	OECD –Europe 20.2 billion USD/year CEE&fSU 18.6 billion USD/y	NA	Low	Tol 2002
Temperature increase	Changes in energy demand for heating	1 °C temperature rise	OECD Europe Central and Eastern Europe and the former Soviet Union	NA	OECD –Europe - 13.1 billion USD/year CEE&fSU - 46.0 billion USD/y	NA	Low	Tol 2002
Temperature increases	Cooling water constraints thermal facilities (nuclear, fossil-fired, geo-thermal, waste incineration)	2020	All Europe	Aquatic ecosystems may be affected by increased water temperatures	Potential loss of capacity and high costs for alternative supplies; reduced security of supply; reduced efficiency/capacity Up to 18.5 10^9 €	Inconveniences because of reduced reliability of supply	High agreement, low evidence	Förster, H., J. Lilliestam, 2009, Paskal, 2011, Greis, 2010
	Decreased transmission capacity	2050	All Europe	NA		NA	High agreement, medium evidence	Rademaekers et al., 2010[1]
	Melting permafrost affecting energy production and distribution in cold climates	2050	Northern Europe	Broken pipelines may lead to oil spills		Inconveniences because of reduced reliability of supply	High agreement, low evidence	ACIA, 2004
	Temperature has an effect on the efficiency of thermal power generation (fossil, biomass), and of	2050	All Europe		Fossil fuel and biomass power will become more efficient at higher temperatures, photovoltaic energy production	NA	High agreement	Rademaekers et al., 2010

Climatic driver or social economic driver	Sub-threat	Time-frame	Area affected[1]	Potential environmental impacts[3]	Potential economic impacts[3]	Potential social impacts[3]	Level of agreement and evidence[2]	References
	Photovoltaic power.				becomes less efficient			
Extreme events (storms) combined with sea level rise	Damage to offshore or coastal production facilities, transmission lines	2050	Coastal areas, northern and western Europe	Flooded coastal or damaged offshore production facilities may lead to pollution	Potential loss of plants and distribution network Up to 16.0 10^9 €	Inconveniences because of reduced reliability of supply	High agreement, low evidence	Rademaekers et al., 2010[1]

[1] The numbers are for climate impacts on nuclear power plants and other electricity technology, related to one ENSEMBLES GCM-RCM combination for the SRES-A1B emissions scenario.

5.8 Infrastructure and transport

5.8.1 Scenarios

Although ground transportation (road and rail), aviation and inland shipping are to some extent vulnerable to climate change, scenarios for infrastructure so far deal with energy use and greenhouse gas emissions (mitigation) rather than with adaptation, for example, for European transport scenarios (EC-DG TREN, 2004; EC-DG-TREN, 2006) . In the context of the Transvision project two initial stereotypical scenarios for the future were explored: a "Cohesive Europe" in which the development of the EU focuses on integrating the populations of the current member states to form a cultural and social homogeneity which emphasizes and a "Competitive Europe", in which the EU will grow to take in neighbouring countries such as Turkey, Ukraine and perhaps even Russia and parts of North Africa, with very different mobility challenges (Tetraplan, 2009). It appears that such scenarios are largely independent on climate change impacts, which may be relevant more for the specific design of transport routes from the perspective of decreasing the vulnerability of the current networks and designing future infrastructure in a climate-proof manner. Also for other infrastructural networks, such as power (see above) and information, no scenarios are known for Europe that can be directly used for the analysis of climate threats. Later in 2011, the Commission will publish a White Paper on the future of transport in Europe with " a vision for a low-carbon, resource-efficient, secure and competitive transport system by 2050 that removes all obstacles to the internal market for transport, promotes clean technologies and modernises transport networks." Supposedly, such a system should also be climate proof. Transport is also covered by energy scenarios (see section 7).

5.8.2 Literature assessment on impacts

Introduction

One can distinguish between two types of vulnerability in the transport and infrastructure sector: the vulnerability of the infrastructure in supporting various types of transportation and mobility, and the dependency on fuel for vehicles, trains, ships and planes. The latter is discussed under "energy" and mainly relates to the vulnerability of biofuels and power generation (for electrification of transport). As to the former, the vulnerability of infrastructure and infrastructural networks (transport, power, communication, drinking water systems, buildings) to climate change has only been identified in a limited number of countries: Finland (Ministry for Agriculture and Forestry, 2005), Sweden (Swedish Government, 2007, Lindgren et al., 2009), Netherlands (van Ierland et al., 2008), and Denmark (Danmark's Energistyrelsen, 2008). In the UK, a study on the impact of climate change on the railway industry was published in 2003 (RSSB, 2010). No comprehensive overview at the European level is as yet available. Outside Europe, vulnerability of infrastructure has been addressed in Australia (Victoria Government, 2006, 2007), Canada (Infrastructure Canada, 2007; PIEVC, 2008) and some of the United States (Alaska, California, Washington, Oregon, Maryland en Florida; see Pew Centre, 2007; NRC, 2008; CSES, 2007). In the transport sector, climate change is mostly considered in a mitigation context.

Climate change affects not only road, rail, aviation and shipping infrastructure, but also the distribution of transportation and traffic flows, e.g. as a result of changing tourism patterns. Conversely, Trans European Network (TEN) plans can affect the vulnerability of other sectors, such as the ecological infrastructure by fragmenting rather than connecting habitats. The 'European Road Transport Research Advisory Council (ERTRAC)' notes that design and simulation tools are needed to better protect road pavements, embankments and bridges against natural hazards such as floods, landslides and earthquakes, and impacts which may result from climate change (ENTRAC, 2004, 2008). Together with the Conference of European Road Directors (CEDR), ENTRAC contributed to the development 2nd European Road Transport Research Arena (TRA). During a conference in Ljubljana, the vulnerability of road networks to climate change in a European context was one of the issues that were discussed (McDonald en Žnidarič, 2008).

With the focus on railways, in 2003 the Rail Safety and Standards Board has published a report on "Railway safety implications of weather, climate and climate change" with the aim to identify the current status of knowledge and to specify the work needed to determine response measures to the threats associated with climate change (RSSB 2003). More work is carried out by the International Union of Railways (UIC). For example, the UIC has started the project "Adapting Rail Infrastructure to Climate Change" (ARISCC) in 2009. Within this project, several railway members are joining forces to gather existing knowledge about climate change in order to develop a new level of management addressing climate change impacts.

Not only road and rail, but also inland waterway transport is vulnerable to climate change impacts, due to low water levels. From an economic perspective, prices rise in periods with low water levels in rivers, leading to welfare losses, while transport flows may adapt to the increase in transport prices by shifting a part of the inland waterway cargo to competing transport modes (Koetse and Rietveld, 2009). Climate change also has an impact on port infrastructure and maritime navigation, as they are sensitive to storminess and wind/wave conditions as well as to sea level in ports and waterways (Policy Research Corporation, 2009). Becker et al (2011) present an overview of threats and adaptation options. PIANC, the global organisation providing guidance for sustainable waterborne transport infrastructure for ports and waterways, established a Permanent Task Group on Climate Change and Navigation which also prepared an overview (PIANC, 2011).

For aviation, until recently in a climate context the attention focused almost exclusively on its contribution to climate change rather than its vulnerability (e.g., IPCC, 1999). More recently, the aviation sector has acknowledged potential climate change impacts, which can be positive (e.g., less heavy snowfall, changed frost conditions, less need for de-icing) or negative or uncertain (e.g., more heavy rainfall/flooding, more storms or changed wind patterns). Since runway capacity losses have major economic consequences, climate effects are of increasing concern to the aviation sector. According to the Swedish Government (2007), a warmer climate may affect ground frost depth with consequences for airfield load bearing capacity, increased precipitation burden on airport storm water systems and it can cause delays in planned maintenance work. The need for de-icing and skid prevention will be reduced in the southern parts of Sweden while increasing in the northern parts. Overall, the Swedish report concludes that aviation is not likely to be affected to any serious extent by climate change. ICAO (2010) provides an overview of the challenges facing civil aviation stakeholders, including impacts related to changes in temperature, snow & frozen ground, precipitation and water supply, sea level, jet stream, convective weather, and visibility. It is also noteworthy that the aviation sector traditionally is well equipped with weather monitoring and communication systems, which contributes to a relatively low vulnerability to climate change.

Various potential positive and negative impacts can be distinguished (Swart and Biesbroek, 2008; Haurie et al., 2009, Jochem and Schade 2009, Cochran 2009):

All transport infrastructure:

- Extreme weather incidences such as snowfall in spring or autumn (causing longer use of winter tires), tempests and rainstorms will impede infrastructure in many respects;
- Periods of heavy rainfall produce flood water, inundation and mudslides which affect all different sectors of the transport system (railway, aviation, navigation, roads);
- Erosion and subsidence of road bases and rail beds, as well as erosion and scouring of bridge supports will pose problems in future years;
- Heat waves lead to more worries about safety and security during construction of roads, rails, bridges etc.;
- Forest fires caused by drought can block the entire infrastructure;
- Thawing of permafrost in the Arctic results in instability of subsurface or even land subsidence. Roads, airstrips and rails have to be stabilised or dislocated;
- Rising sea levels will cause interruption or even loss of low-lying infrastructure in coastal areas and little islands;
- Coastal flooding (also as a consequence of surges) will result in great damage and migration to the interior will overstrain the infrastructure there;
- Increased monitoring and maintenance.

Rail:

- The temperature in rails, if stable (high or low), can be managed. E.g., to avoid freezing and blocking, switches and crossing are provided with a heating system in cold climates. Long hot periods can be dealt with by a different setting of pre-tension in rails;
- What is disturbing is not the absolute temperature, but sudden, not foreseen changes. When extreme heat during daytime is followed by a cold night this will cause deformation of rail lines which could eventually lead to derailments; trains would have to run more slowly and with more distance between each other to avoid rails heating up due to braking; decreased payload capacity;
- Higher probability of fire along railway lines in long hot and dry periods. Those fires can be easily caused by incandescent particles originated by braking. This is already a problem in southern Europe which could be aggravated by climate change;
- ‘Thermal’ problems concerning the overhead contact line;
- In urban areas people may use other transport options instead of underground railways because of the unbearable heat;

- Extreme events can lead to damage, for example due to extreme quantities of snow, fallen trees or flooded tunnels. Floods on railway lines can have disastrous effects for track stability;
- Positive: Rails would freeze more rarely.

Road:

- Rising temperatures lead to increased rutting and softening of asphalt;
- In warm weather risky and drunk driving is more likely;
- More accidents on roads because of lack of concentration as a result of heat inside cars;
- Using air conditioning appliances in cars results in more energy expenditures;
- Vehicle overheating and tire deterioration;
- Thawing of permafrost will enhance the risk of rock slides and avalanches in Alpine regions, leading to interruptions in road traffic;
- Warming winter temperatures shortened the season for ice roads that provide vital access to communities and industrial activities in remote areas;
- Positive: streets would be safer owing to less snowfall;
- Positive: less damage due to freezing in pavements, but on the other hand, numerous freeze-thaw cycles may harm the streets;
- Streets are affected by extreme weather such as broken down cars, closed and damaged roads because of fallen trees;
- Changes in landscaping and road-side vegetation due to a different temperature and precipitation regime;
- Mobility or accessibility problems as a result of flooded road stretches, or tunnels, overloading of drainage systems;
- Heavy rainfall leads to soil erosion which can lead to subsidence of streets.

Aviation:

- High temperatures lead to increased rutting and softening of asphalt;
- Lower air pressure as a result of the heat leads to reduced carrying capacity, and more airport runway length and fuel is needed. Cancellation of flights may happen in a very few specific airports around the world (the so called "hot & high" airports);
- More frequent storms can lead to delays, cancellation of flights and cases of emergency.

Navigation:

- Periods of low rainfall inhibit inland waterway transportation, because low tide forces the ships to reduce cargo weight. Possibly navigation may have to be stopped temporarily;

- Water sharing and allocation conflicts;
- Increase in silt deposits and increased vegetation growth leading to increased maintenance;
- Closing down navigation may also be necessary because of high water in rivers;
- Severe storms will impair ports, while containers could get lost at sea by falling overboard;
- Positive: northern harbours would be ice-free for longer periods, providing the opportunity for new, rather longer use of navigation routes;
- Positive: deeper water due to sea level rise would permit greater ship drafts.

Ideally, the climate resilience of investments in trans-European networks should be evaluated during the strategy development stage, but particularly in the stage of detailed design, since the potential impacts can mostly be associated with vulnerability of local infrastructure.

Economic impact

The Weather project analyses the costs of more frequent and more severe weather events on the transport sector and explores the costs and benefits of adaptation measures. The project focusses on the transport transport modes; road, air, waterborne and rail. The total costs found for road damages are roughly 1.8 billion Euro annually. Of these damages 35% are related to infrastructural damages by heavy precipitation and floods alone. In the winter floods create roughly 80 percent of the total damages (Enei et al. 2011). The total annual costs of extreme events for railways are roughly 0.3 billion Euro. The assessment of European media and transport sector data lead to €m7.0. per heavy precipitation event, €m45 for permanent rain with flooding, €m0.9 per thunderstorm, €m2.5 per winter storm and €m5.6. per avalanche. Of the dominating rain and flood costs 40% are attributed each to infrastructure assets and to operations, while the remaining 20% are borne by users through delays (Enei et al. 2011). The annual costs of weather extremes for air transport system are roughly 0.4 billion euro annually (Enei et al. 2011).

European legislation

European transport, energy and telecommunications infrastructures have been designed along national lines and need to be harmonised, connected and integrated into the wider European context via the Trans-European Networks (TENs). In 1996 Community guidelines for the development of the trans-European transport network (TEN-T) were agreed upon as the general reference framework for the implementation of the transport network and for identifying projects of common interest. The guidelines aim to integrate national networks and modes of transport, linking peripheral regions of the European Union to the centre, and improving safety and efficiency of the networks. They cover roads, railways, inland waterways, airports, seaports, inland ports and traffic management systems, serving the entire EU- territory, carrying the bulk of the long distance traffic and tying the EU's geographical and economic regions closer together. The guidelines were revised in 2001 and 2004 (EC, 1996, 2001, 2004). These guidelines call for infrastructure for transport modes that cause less damage to the environment, namely rail transport, short sea shipping and inland waterways shipping. They also require the assessment of the effects of plans and programmes on the environment and require funding for transport infrastructure to be conditional on compliance with environmental legislation. However, they do not (yet) require an assessment of the vulnerability with regards to climate resilience of transport infrastructure. EC (2007) focuses on integration and long-term challenges for TENs (transport, energy, telecommunication) but does not address vulnerability to climate change. The 2009 Green Paper on the future of TEN-T focuses on mitigation but also notes that "policy should take account of the need to adapt to the possible consequences of climate change (such as rising sea levels or changing heat patterns)" and that "the vulnerability of the TEN-T to climate change and potential adaptation measures should therefore be assessed, and attention should be given to the question on how to "climate proof" new infrastructure (EC, 2009). For aviation, EU policy focuses on the contribution to climate change rather than the vulnerability (e.g., EC, 2005).

Finally, an overarching EU policy with relevance to adaptation is the Regional Policy with Cohesion and Structural Funds. The policy pursues the objectives of Convergence, Regional Competitiveness and Employment, and Territorial Cooperation. In many of the supported projects climate resilience plays a role within the areas of planning, building and financing. Education programs funded under the umbrella of EU regional policy can be used for adaptation purposes. The potential impacts can also affect investments by Cohesion and Structural funds – as soon as structures are involved that are exposed to any of these impacts. E.g., this is the case in urban development projects aiming to increase the touristic value of a city, improving its transport net or protecting its natural environment. Hence, while it is acknowledged that reducing the vulnerability of transport and infrastructure is important, no concrete measures are proposed yet. Lack of knowledge on damage costs as well as costs of adaptation seems a bottleneck. In order to make sensible decisions one should be able to compare the investment costs for the measures with the damage costs they aim to avoid. Concrete and preferably quantitative assessments of consequences of climate change and associated costs are hardly available. Cohesion policy and TEN funds offer many opportunities, and EC (2010) notes that both the scope and scale of financial engineering instruments might be extended to address climate change, amongst many other challenges. As the financial plan foresees relatively large amounts of financial resources spent in the Regional Policy (more than 40% of total EU resources) it should be carefully screened for aspects related to adaptation.

Socio-economic developments affecting exposure, sensitivity and adaptive capacity

Various socio-economic developments can influence vulnerability, such as increased infrastructure development and economic investments in vulnerable areas, such as flood-prone areas. No assessment in this context has yet been performed for Europe.

5.8.3 Damage and adaptation costs

Table 5.22: Damage costs Infrastructure and transport

	2025		2080	
Sectors	**Estimated Damage Costs**	**Sources for Damage Estimates**	**Estimated Damage Costs**	**Sources for Damage Estimates**
Infrastructure and transport	High	Nordhaus Boyer 2000	High	Nordhaus Boyer 2000

Table 5.23: Adaptation costs Infrastructure and transport

Sectors	Themes	Adaptation costs (qualitative)	Sources	Notes
Infrastructure and transport	Road	High (up to 2050)	Jochem and Schade 2009	"Educated guess" without empirical backing, low coverage of quantitative cost assessments, but existing studies indicate high costs
	Rail			
	Aviation	Low (no indication of time frame)		Not many adaptation measures available – sector is already well equipped with weather-monitoring systems
	Shipping	Medium (no indication of time frame)		Main costs arise in connection to infrastructure, minor costs due to adaptation of vessels

5.8.4 Summary

Summarizing main problems

Flooding of ports may lead to pollution of sea and coast. Railroad and road infrastructure may have to adapt to flash floods, but they may not be frequent and variable in location, as is summer precipitation. Patterns of ice and snow may become more unpredictable.

Knowledge Gaps

Impacts are only available for a few EU countries with a bias towards Scandinavian countries; nothing is available on southern and eastern Europe. There is very little information on socio-economic aspects. Concrete and preferably quantitative assessments of consequences of climate change and associated costs are hardly available.

Table 5.24: Summary table Infrastructure and transport

Climatic driver or social economic driver	Sub-threat/opportunity	Time-frame	Area affected[1]	Potential environmental impacts[3]	Potential economic impacts[3]	Potential social impacts[3]	Level of agreement and evidence[2]	Reference
Changes in temperature	Lower damage to roads and railways in winter, higher in summer	Gradually increasing 2020	Europe-wide	NA	Increased monitoring and maintenance	Choice of different transport mode by public; more risky driving	Low/low	Swart and Biesbroek, 2008, Haurie 2009, Jochem and Schade 2009
	Thawing of ice roads and permafrost leads to road and rail instability	2020	Northern Europe (Arctic) and Alpine region	Erosion	Maintenance cost	Isolation of communities	Medium/medium	Jochem and Schade 2009
	Ice free shipping	Long-term 2080	Northern Europe (Arctic)	Pollution if accidents	Positive	Employment (+)	Medium/low	Swart and Biesbroek, 2008, Haurie 2009
Change in precipitation	Inland shipping problems due to low water levels	Gradually increasing 2020	Major rivers	Move to less eco-efficient transport modes	Increased freight prices and move to other modes minor	Employment (-) major	High/medium	Koetse and Rietveld, 2009
	Flooded roads, tunnels, railways	Gradually increasing 2020	Europe-wide	NA	Disrupted economic activity minor	Traffic disruptions, inconvenience	Medium/low	Swart and Biesbroek, 2008, Haurie 2009
	Overloaded storm water disposal system	Gradually increasing 2020	Europe-wide	Pollution of surface waters	Small minor	inconvenience	Medium/low	Swart and Biesbroek, 2008, Haurie 2009
Changing wind patterns	Damage by high winds (railways)	Unknown	Europe-wide, coastal areas	NA	Losses due to runway closure minor	inconvenience	Low/low	Swart and Biesbroek, 2008, Haurie 2009

Climatic driver or social economic driver	Sub-threat/opportunity	Time-frame	Area affected[1]	Potential environmental impacts[3]	Potential economic impacts[3]	Potential social impacts[3]	Level of agreement and evidence[2]	Reference
	Changed runway availability airports	Unknown	Europe-wide, coastal areas	NA		inconvenience	Low/low	ICAO, 2010
Rising sea levels, combined with storm surges	Flooding coastal roads, port facilities	Gradually increasing 2050	coastal areas	Pollution of sea water and beaches	Damage, economic disruption **major**	safety	Low/low	Policy Research Corporation, 2009
Weather extremes	Floods, droughts, precipitation, storms, etc	Current	EU	NA	Road: €1.8 B/year Rail: €0.3 B/year Air: € 0.4 B/year		Low/Medium	Enei et al, 2011

(note: vulnerability as a result of increased dependence on biofuels, electricity, see energy)

5.9 Industry and Services, including Tourism

5.9.1 Scenarios

No specific scenarios have been identified in a specific climate context for specific types of industry, manufacturing or services other than tourism. In general, the vulnerability of specific sectors can be assumed to be covered under other sectors. E.g., the food and beverage industry is clearly dependent on water. Misuraca et al. (2010) develop four scenarios for the development of the ICT industry in Europe, focusing on governance questions, along two axes of openness and transparency, and integrated policy intelligence. Climate change was one of the factors noted as a major challenge on the basis of an inventory of 30 foresight studies, policy reports and scenarios, but is considered as part of the global context, rather than as a driver directly influencing the sector.

As to tourism, Amelung and Moreno (2009) analyzed the potential impacts of climate change (using A2 and B2 SRES climate model results) on tourism in Europe, using the tourism climatic index (TCI), based on the notion of “human comfort” as a basis (Figure 15). They note the significant potential impacts on winter tourism as a result of decreasing snow reliability and on summer tourism because of deteriorating thermal conditions in southern Europe. The latter is expected to be exacerbated by increasing water shortages because of decreased run-off and increased demand from agriculture, residential areas, the energy sector and nature. Northern European regions on the other hand may benefit. Like earlier studies, Amelung and Moreno (2009) analyse the potential impacts of climate change on tourism without considering other factors that may change tourist behaviour. Figure 8 gives one example for one climate model and two scenarios of the possible overall development of the TCI. The study also looks at other climate models and seasonal effects.

Scenarios for the development of tourism independent of climate change are often developed to explore the possible future opportunities and threats for particular locations or types of tourism (e.g., ecotourism). The World Tourism Organization (WTO, 2004) in its long-term forecast expects that Europe maintains its position as top receiving region in the world for total tourist arrivals by region by 2020, growing by more than 3 % annually from 527.3 in 2010 to 717 million tourists by 2011. Europe’s share however is projected to decrease from to 60% in 1995 to 46 % in 2020, because the European tourism industry faces strongly increasing competition from other destinations and other goods and services, exacerbated by cheap air fares and improved facilities elsewhere. Climate change will affect tourism worldwide, so the level to which climate change would aggravate the downward pressure of Europe’s share of the world’s tourism industry is as yet unpredictable.

WTO (2004), which did not incorporate climate change considerations in its outlook, also projects a relative shift in European tourist destinations, with the Mediterranean remaining the most popular region, and Central/Eastern Europe expected to attract more visitors than Western Europe in the future.

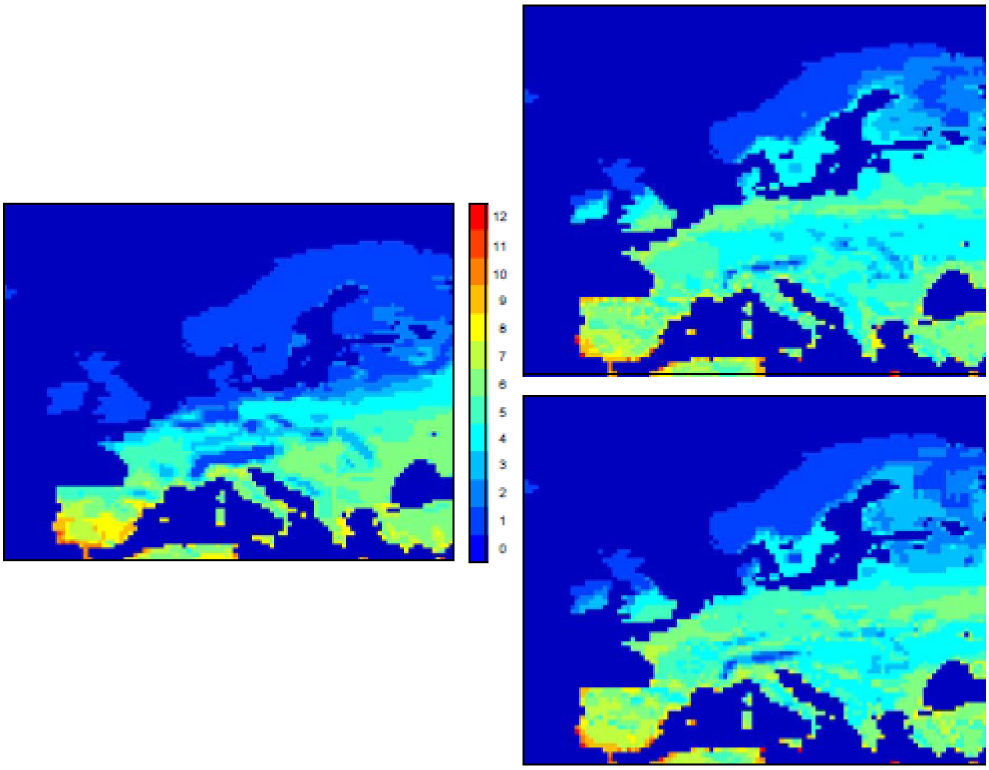


Figure 15: Average number of months per year with very good conditions or better (TCI>70), in the 1970s (left) and the 2080s (right), according to the RCAO model, A2 (top) and B2 (bottom) scenarios (source: Amerlung and Moreno, 2009)

5.9.2 Literature assessment on impacts

Introduction

Climate change influences Europe's industrial sector, services and tourism industry in various ways.For industry the main issues are availability of process water, cooling water and the risk of flooding. , Increasing temperatures in a number of European regions seem to improve the tourism sector, providing opportunities for growth. Extreme events such as floods and storms can affect the tourism sector negatively.

Climate change is seldom the main factor in considering stresses on the sustainability of industries. Social, economic and institutional processes to a large extent influence the industrial sector. Therefore, when studying the impacts and threats of climate change, these impacts should be considered in a multi-cause context.

Industry is often capable of considerable adaptation, although this depends heavily on the competence and capacity of individuals, communities, enterprises and local governments, together with access to financial and other resources. Many industrial sectors have good reasons not to look beyond the next five years, but the development of adaptation options may take longer than five years, so the generally short term attitude may lead to missed opportunities. The adaptive capacity is limited especially when industry is confronted with climatic changes that are relatively extreme or persistent.

European legislation

A variety of laws and legislation exists in Europe related to industries, trade, services and tourism. We briefly mention the Water framework directive and the Drinking water directive for industries depending on water resources; agricultural policy for production of food crops and raw materials, and an extensive body of economic regulations to create a fair market. It is beyond the scope of this assessment to go into all of these legislative documents. The EU legislation related to tourism will be discussed more extensively.

During a meeting of the European ministers of tourism in April 2010 steps were taken towards committing the Union and all its Member States to a competitive, sustainable, modern and socially responsible tourism sector. The EU ministers for tourism supported the 'Madrid Declaration', which establishes a series of recommendations concerning the implementation of a consolidated European tourism policy, stressing the need to strengthen sustainable competitiveness within the sector and recognising the added value of action by the EU on tourism while providing a valuable complement to individual action by the Member States through an integrated approach to tourism.

To achieve these objectives, actions promoting tourism may be grouped under the following four priorities:

1. Stimulate competitiveness in the European tourism sector;
2. Promote the development of sustainable, responsible and high-quality tourism;
3. Consolidate the image and profile of Europe as a collection of sustainable and high quality destinations;
4. Maximise the potential of EU financial policies and instruments for developing tourism.

These four priorities provide the skeleton for a new action framework for tourism which the Commission intends to implement in close cooperation with the Member States and the principal operators in the tourism industry (European Commission 2010).

Socio-economic developments related to industry and services, including tourism

Few characterisations have been developed that relate specifically to climate change impacts on industry. The studies that have been done have common roots in the perspectives embedded in the IPCC Special Report on Emission Scenarios (SRES) as the drivers in the SRES scenarios (population, economic growth, technology and governance) are all very relevant for the development of industries. One of the key factors influencing industry, services and to a lesser extent tourism is population growth and related urbanization as many of these people depend on industry, services and infrastructure for jobs, well-being and mobility. More valuable assets and activities are likely to become exposed to climate risks, but it is assumed that the economic potential to respond will also increase. Economic development will be central to adaptive capacity, as well as an enabling governance structure (Wilbanks et al. 2007).

Specifically for tourism, strong growth is expected in the coming decades in the East Mediterranean sub-regions as well as countries in Central and Eastern Europe. The rapid increase in number of low cost airlines throughout Europe will continue to boost intraregional travel due to the low costs of fares. The travel and tourism industry in Europe must offer a broader range of options in the coming decades as its customers become more diverse and demanding (e.g. increased number of single parent households, increasing environmental awareness) (World Tourism Organization 1997).

Industry

Industry in this section refers to manufacturing, mining, construction and related informal production activities. The transport, energy and infrastructural sector partly overlap with the industrial sector. However, since they are separately addressed in this report, the main focus lies on the activities as mentioned previously.

The industrial sector is generally thought to be less vulnerable to the impacts of climate change than other sectors, such as agriculture and water services. This is partly because the sensitivity to climatic variability and change is considered to be comparatively low in the industrial sectors and partly because industry is perceived as having a high capacity to adapt in response to climate change. For example, many industries already choose to close their water cycle because of limitations on waste water from the Water Framework Directive. However, there are industrial sectors which are considered to be especially vulnerable to climate change. These are industrial facilities located in climate-sensitive areas (e.g. river and coastal areas), industrial sectors dependent on climate-sensitive inputs (e.g. food processing) and industrial sectors with long-lived capital assets. For the construction industry, a higher temperature may result in less inhibitions of the building process due to frosty days.

Impacts and threats from climate change are mainly related to extreme weather events rather than to gradual changes in climate. However, negative impacts can occur when possible thresholds are reached through gradual changes. Floods and storms can cause considerable damage to industrial facilities, which in turn can lead to severe air and water pollution. Furthermore, extreme events threaten linkage infrastructure such as bridges, roads, pipelines or transmission networks which can cause substantial economic losses. Less direct impacts on industry can also be significant. Sectors dependent on climate-sensitive inputs for their raw materials, such as the food processing and pulp and paper sectors, are likely to experience changes in sources of major inputs. Availability of surface water for production processes and cooling is an issue for several large industries. Prolonged droughts in regions where this has not been a climate pattern in the past can cause industries to choose a different location (along the coast for cooling water; to groundwater resources for process water). For some industries a deteriorating water quality due to higher temperatures can be a problem. In the longer term, both extreme events and gradual changes in climate can cause regional shifts in production of specific goods and services.

Retail and commercial services

Climate change has the potential to influence every link in the supply chain, including the efficiency of the distribution network, the health and comfort of the workforce and consumption patterns. Many retail and commercial services are more difficult to move than industrial facilities, as their locations are focussed on where most of the people are living. Therefore retail and commercial services are in principal more vulnerable to climate change.

Distributional networks for commercial activities can be affected in a variety of ways. Changing winter road conditions and strong winds can negatively influence the transport of goods, both by road and by sea. Transportation routes in permafrost zones may be negatively affected by higher temperatures which shorten the winter road season. Coastal infrastructure and distribution facilities are vulnerable to inundation and flood damage. Drought events can negatively influence river transport by inland waterways.

Perishable commodities are one of the most climate-sensitive retail markets. Climate change might alter the sourcing and processing of agricultural products, and climate change policies (e.g. a carbon tax or an emissions offset payment) may further alter the geographical distribution of raw materials and product markets (Wilbanks et al. 2007).

Insurance

The insurance system differs widely between countries in Europe, as does the value of properties at risk. While insurers are in principle able to adapt quickly to new risks, the uncertainties accompanying climate change make it difficult for insurers to respond to this new threat.

The uncertainty of future climate as well as socio-economic development leads to a wide range of estimates for the costs of future climate induced damage, for example flood damage. For instance, annual river flood damage in the UK is expected to increase between less than twice the current level of damages under the B2 scenario to more than twenty times under the A1 scenario by 2080. Future insurance costs are expected to rise significantly with extreme events as the costs of infrequent catastrophic events are much higher than more frequent events (Alcamo et al. 2007). Property insurance coverage will expand with economic growth. Along with the difficulty of meeting the financial burden of the rising costs of a disaster comes the problem of handling the claims. For the finance sector, climate change related risks are increasingly considered for specific 'susceptible' sectors such as hydroelectric projects, irrigation and agriculture, and tourism (Wilbank et al. 2007).

Tourism

Tourism is a major economic sector in Europe, with the current annual flow of tourists from Northern to Southern Europe accounting for one in every six tourist arrivals in the world. Climate change has the potential to radically alter tourism patterns in Europe by inducing changes in destinations and seasonal demand structure (Ciscar et al. 2009). The likely effects of climate change on the tourism sector vary widely, depending on the location and the season. Within the Peseta project the economic impact of climate change in different European regions was projected. A stable total amount of tourism expenditures was assumed. The PESETA project projected shifts between regions in 2080. Most regions benefit from climate change (Northern Europe (0.3 – 2.4 billion a year), British Islands (0.5 – 3.4 billion a year), Central Europe North (0.4 – 2.3 billion a year) and Central Europe South (0.6 -5.0 billion a year)). Tourism expenditures in Southern Europe are projected to decline by 1.7 – 12.8 billion Euro a year (Ciscar et al, 2009).

In spring, better conditions for tourism are expected to prevail in both Northern and Southern Europe. Some scenarios even foresee good to excellent conditions in spring in the Mediterranean region at the end of the 21st century, while good conditions are projected to be more frequent in France and the Balkans. In the northern part of continental Europe, conditions improve markedly as well, from marginal to good or even very good (Ciscar et al. 2009).

In summer, the zone of good conditions expands towards the north. Conditions could become excellent throughout the northern part of continental Europe, as well as in Finland, southern Scandinavia, Southern England and along the east Adriatic coast. However, increasing temperatures and decreasing precipitation seem to be a disadvantage to Southern Europe. In parts of Spain, Italy and Greece, the Tourism Comfort Index (TCI) developed by Amelung and Viner (2006) drops from excellent or ideal conditions to marginal conditions towards the end of the 21st century (Ciscar et al. 2009). Droughts and arid environments make these regions less comfortable for tourists (Wilbanks et al. 2007). At the same time, mountainous parts of France, Italy and Spain could become more popular because of their relative coolness (Alcamo et al. 2007).

Changes in autumn are more or less comparable to the ones in spring. The TCI improves throughout Europe, with excellent conditions covering a larger part of southern Europe and the Balkans (Ciscar et al. 2009).

In winter, climate change is expected to influence the winter sport industry considerably. In central Europe, the ski industry is likely to be disrupted by significant reductions in natural snow cover especially in the beginning and the end of the ski season (Alcamo et al. 2007).

Higher summer temperatures may lead to a gradual decrease in summer tourism in the Mediterranean but an increase in spring and perhaps autumn. The occupation rates associated with the resulting longer tourism season in the Mediterranean will spread demand more evenly over the year and thus alleviate the pressure on summer water supply and energy demand (Amelung and Viner 2006). For currently overexploited aquifers in tourist zones a more evenly spread tourism season could be beneficial (Amelung and Moreno 2009). In particular the increasingly favourable conditions in northern Europe might lead to more domestic tourism in north-west Europe (Wilbanks et al. 2007). Overall, under the influence of climate change, tourist season lengths would become much more evenly distributed across Europe (Amelung and Moreno 2009).

5.9.3 Damage and adaptation costs

Table 5.25: Damage costs Industry and Services, including Tourism

	2025		2080	
Sectors	**Estimated Damage Costs**	**Sources for Damage Estimates**	**Estimated Damage Costs**	**Sources for Damage Estimates**
Industry and Services, including Tourism	Low (Tourism: High in Alpine areas and Negative in North)	Stern Review	Low (Tourism: High in Alpine areas and Negative in North)	Stern Review; PESETA; ADAM

Table 5.26: Adaptation costs Industry and Services, including Tourism

Sectors	Themes	Adaptation costs (qualitative)	Sources	Notes
Industry and services	Industry	Low (no indication of time frame)	UNFCCC 2007	Threats and opportunities, low coverage, no quantitative cost estimates available
	Financial sector	Low (no indication of time frame)		Threats and opportunities in insurance sector
	Tourism	High (no indication of time frame)		Threats and opportunities, high costs in winter ski resorts

5.9.4 Summary

Summarizing main problems

The industrial sector is generally thought to be less vulnerable to the impacts of climate change than other sectors, such as agriculture and water services. Retail and commercial services are more vulnerable to climate change. Still the industrial sector can be affected by extreme weather events such as storms and floods leading to considerable damage to industrial facilities and infrastructure. Transport routes are affected by higher temperatures as well as by floods and droughts. This especially affects perishable commodities. Significant rises in insurance costs are expected, especially in relation to extreme events. The likely effects of climate change on the tourism sector vary widely, depending on the location and the season. In general, under the influence of climate change, tourist season lengths will become much more evenly distributed across Europe.

Knowledge Gaps

Specific numbers related to the impacts of climate change on industry, services and tourism are hardly available.

Table 5.27: Summary table Industry and Services, including Tourism

Climatic driver or social economic driver	Sub-threat/ opportunity	Time-frame	Area affected[1]	Potential environmental impacts[3]	Potential economic impacts[3]	Potential social impacts[3]	Level of agreement and evidence[2]	Reference
Changes in climatic conditions	**Changes in attractively of tourism locations**	**2080**	**Europe**		**Northern Europe** **0.3 – 2.4 billion Euro/year** **British Islands** **0.5 – 3.4 billion Euro/year** **Central Europe North** **0.4 – 2.3 billion Euro/year** **Central Europe South** **0.6 – 5.0 billion Euro/year** **Southern Europe** **- 1.7 to – 12.8**		**Low**	**Ciscar et al 2009, PESETA project**
Changes in temperature	Health and comfort of workforce threatened	2020	Southern Europe and megacities		Decreased productivity	Increasing absenteeism Health problems	High/low	Wilbanks et al. 2007
	Difficulties in road transport	2050	Northern Europe		Loss of goods, especially perishable commodities	Loss of income	High/ low	Wilbanks et al. 2007
	Better tourism conditions in spring and autumn	2100	Northern and Southern Europe, Balkans	More evenly spread water supply and energy demand	Increase in spring and autumn tourism numbers Increase in tourism	Increasing incomes in spring and autumn More domestic tourism	Medium/ high	Amelung and Moreno 2009; Amelung and Viner 2006; Wilbanks et al 2007; Ciscar et al.

Climatic driver or social economic driver	Sub-threat/ opportunity	Time-frame	Area affected[1]	Potential environmental impacts[3]	Potential economic impacts[3]	Potential social impacts[3]	Level of agreement and evidence[2]	Reference
					facilities			2009
	Better tourism conditions in summer	2100	Northern part of continental Europe, Scandinavia	More pressure on natural resources and environment	Increase in summer tourism numbers Increase in tourism facilities	Increasing incomes in summer	Medium/ mediun	Ciscar et al. 2009; Amelung and Moreno 2009
	Worse tourism conditions in summer	2100	Southern Europe (non-mountainous areas)	Decreasing pressure on summer water supplies and energy demand	Gradual decrease in summer tourism	Decreasing incomes in summer	Medium/ high	Ciscar et al. 2009; Amelung and Moreno 2009; Amelung and Viner 2006
Change in precipitation	Water shortage for food processing, pulp and paper, and other water-dependent industries	2020	All of Europe; the South more severely	Less water available for nature	Production losses, relocation of industry dependent on cooling from rivers to coast, swtch to closed water cycle	Competing claims in water	High/high	Wilbanks et al. 2007
	Altered geographical distribution of raw materials	2050	All of Europe		Alterations in sourcing and processing of agricultural products		Low/low	Wilbanks et al. 2007
	Changing precipitation patterns during winter season	2050	Positive for Northern Europe, negative for Central Europe		Increased (northern) and decreased (centra Europe) ski industry activities	Increased (northern) and decreased (central Europe) seasonal incomes	High/high	Alcamo et al. 2007; Ciscar et al. 2009
	Expansion of droughts and arid environments	2100	Southern Europe (non-mountainous areas)	Desertification	Decrease in tourism numbers	Decreased income from tourism	High/low	Wilbanks et al. 2007
Rising sea levels, combined with	Damage to industrial facilities	2050	Industrial concentrations along the European sea		Inundation and flood damage		High/low	Wilbanks et al. 2007

Climatic driver or social economic driver	Sub-threat/ opportunity	Time-frame	Area affected[1]	Potential environmental impacts[3]	Potential economic impacts[3]	Potential social impacts[3]	Level of agreement and evidence[2]	Reference
storm surges			coast		Significant rises in insurance costs			
	Damage to linkage infrastructure such as bridges, roads, pipelines or transmission networks	2050	Industrial concentrations along the European sea coast		Higher costs for logistics	Regional shifts in production of specific goods and services	High/low	Wilbanks et al. 2007

5.10 Health

5.10.1Scenarios

While various scenario studies on climate change and health have been published, for Europe Watkiss et al (2009) is probably the most recent and comprehensive published analysis. Using climate change model results for SRES A2 and B2, they analyse the positive and negative health effects of climate change in Europe and its regional variation, capturing increases in summer heat related mortality (deaths) and morbidity (illness); decreases in winter cold related mortality and morbidity; changes in the disease burden e.g. from vector-, water- or food-borne disease; increases in the risk of accidents and wider well being from extreme events (storms and floods). They assess the physical and economic costs of health impacts, that may amount yearly to tens of thousand of additional deaths and tens of billions of Euros for heat and cold related mortality, and tens of thousands of cases and billions for food borne diseases, respectively. Figure 16 demonstrates that the (distribution of) climate effects on mortality very much depends on the choice of exposure response function. For example, with climate dependent functions (based on statistical relationships), the rise in premature heat related mortality is greater than the decrease in cold related mortality, while for the country specific functions (based on epidemiological studies), the opposite occurs (cold related mortality benefits are significantly greater, see Watkiss et al., 2009 for more details). Also acclimatization plays a key role for the eventual impacts.

In addition to climatic change, also other factors play a role in determining potential health impacts, such changes in the number of people and their geographical location and changes in the age structure and death rate of the population, which is important because of the fact that Europe has an aging population. Watkiss et al. (2009) take the population assumptions at the country level from the SRES implementation at IIASA.

The CEHAPIS project addresses the health impacts of climate change in detail and even more comprehensively in an as yet unpublished report (WHO, 2011), drawing on similar climate scenario work as Watkiss et al. (2009). WHO (2011) however discusses a few additional impacts which are relevant from a European perspective, such as the effects of climate change on air pollution, food safety, and allergic disorders. Scenario analysis relating air pollution to climate change has focused on the co-benefits of greenhouse gas emissions reduction on air pollution and health. Less researched is the question to what extent climate change makes it more difficult to reach air quality objectives. Ozone is formed by complex chemical reactions in the atmosphere. Temperature can be used as a surrogate for the meteorological factors influencing surface ozone formation (Jacob et al., 1993, Camalier et al., 2007) Sunlight availability also plays a role in these reactions. Changes in the number of sunny days affect the amount of ozone that is formed. In western-Europe the summer smog problem is dominated by the large scale transport of air. (Smeets &

Beck, 2001). Changes in wind patterns effect the distribution of ozone.

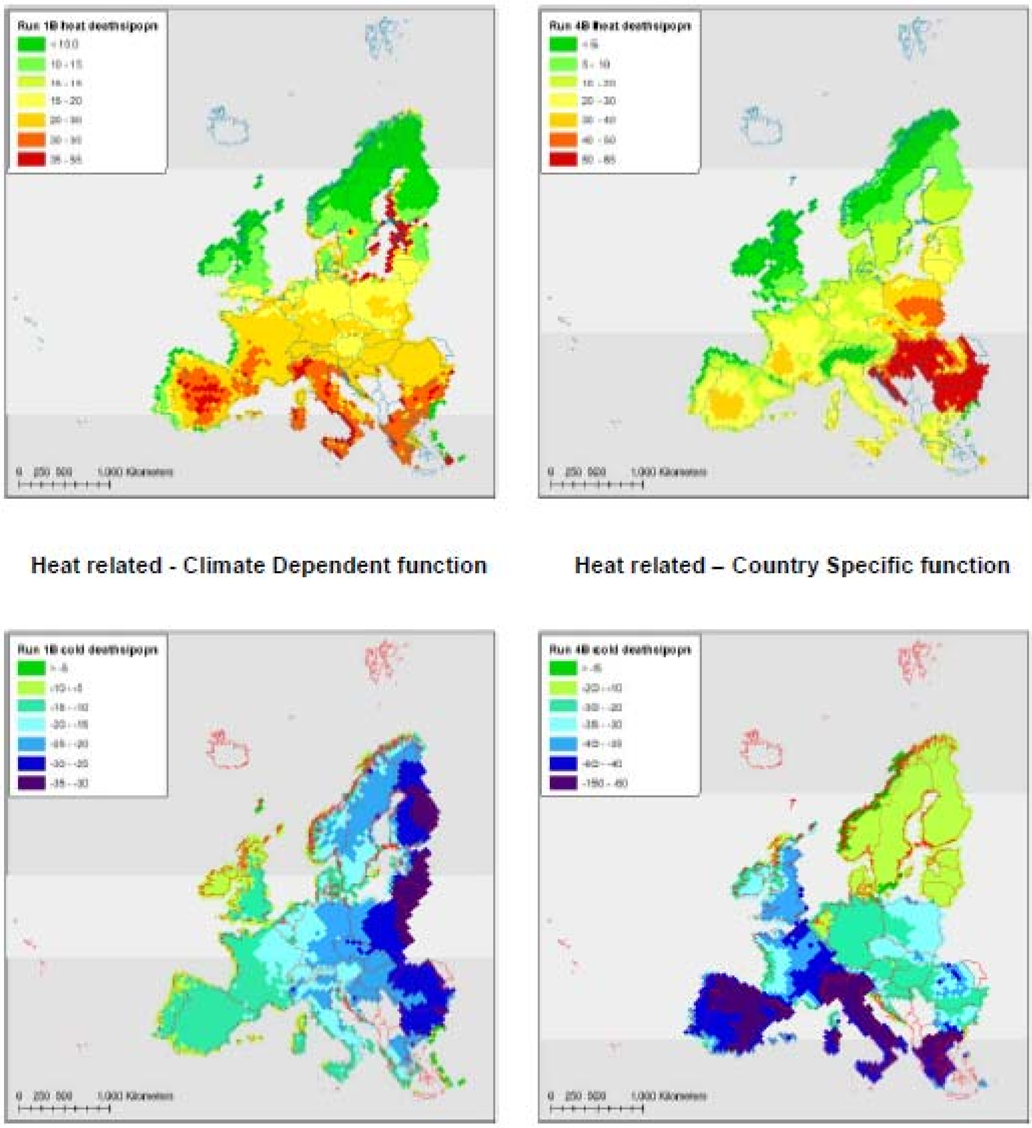


Figure 16: Average annual heat-related and cold-related death rates per 100,000 population, for 2071-2100 A2 scenario, using the HS1 climate data. Climate-dependent and country specific health functions (no acclimatisation / decline in the sensitivity of mortality to cold). Source: Watkiss et al (2009).

The large number of premature deaths during the 2003 heat wave was not only due to the high temperatures, but also to the deficiencies in the health care systems. Therefore, in order to evaluate the importance on non-climate factors for future health in Europe, a broader set of scenarios would be useful, e.g. to evaluate the adaptive capacity of the health care system in Europe and its member states. Unfortunately, such scenarios are not available. Available studies often focus on the expected health care costs. In the FP5 project AGIR, alternative scenarios were developed for 2050 for health, life expectancy and social expenditure, assuming that that people may live substantially longer in the future than estimated by common demographic projections, and may spend part of these additional years in better health (Schulz, 2005). An analysis of the effects on health care and pension expenditures and government finances in the EU suggests that the negative effect of living longer on expenditures and government finances may more or less be balanced by the positive effect of better health (Pellikaan and Westerhout, 2005). The very large amount of resources involved in these matters suggest that the impact of climate change on health in an aging population can have very large economic consequences, as also found by Watkiss et al. (2009).

5.10.2Literature assessment on impacts

Introduction

Climate and weather has a powerful impact on human health. In general climate change is not expected to create many new or unknown health threats, but it will increase the interaction between the environment and human health (EU, 2009). This can lead to worsening of diseases and changes in the distribution of diseases. Climate changes can effect human health directly by thermal stress and casualties and injuries of extreme events (storms and floods), and indirect by changes in distribution of vector borne diseases, water borne diseases and air quality (Ciscar et al, 2011). The biggest risks are expected to be from an increase in the frequency of extreme weather events, changes in environmental determinants of health and changes in the geographical distribution of infectious diseases (EEA, 2009). These effects have economic consequences, for example trough medical costs and lost time at work (EU commission, 2007). The relation between human health and climate change are complex and interact with several other factors. The WHO regional office for Europe concludes that health services play an important role in indentifying, advocating and adapting to climate change. EU effects of climate change on food security and safety, and indoor climate are not taken into account.

Agrawala et al. (2010) performed a global study on the impact of climate change and the costs and benefits of adaptation. For health this study builds on earlier studies by Tan and Shibasaki (2003), Rosenzweig and Parry (1994) and Nordhaus and Boyer (2000). According to Agrawala et al. (2010) the health related damages in Europe for a 2.5 °C global temperature rise are 0.02 % of the GDP.

European legislation

The European commission recognizes the climate related risk to health issues. According to the White paper 'Adapting to climate change; towards an European framework for action' it is important to increase the resilience of health and social systems and control climate related health impacts. The white paper included a working document on human, animal and plant health impacts on climate change (2009). The commission mainstreams climate change issues in the EU health strategy. Climate change should become a part of this strategy.

Summer heat and winter cold related deaths

According to the white paper impact assessment the primary concern in Europe is the mortality and morbidity related to heat. When temperatures rise or fall beyond the level human populations can cope with, stress occurs. As a result of climate change temperatures rise globally. Higher temperatures lead to an increase of heat related mortality and a decrease of cold related mortality. People become more sensitive to heat waves if the duration is longer. The sensitivity is country specific and is a result of differences in physiological and social conditions. In general older people are more sensitive to extremes high temperatures. Cities are extra vulnerable for heat stress as a result of the urban heat island effect. According to the Euroheat project (D'Ippoliti, 2010) the increase in mortality during heat wave days ranged from + 7.6% in Munich to + 33.6% in Milan. The increase was up to three times greater during episodes of long duration and high intensity. Pooled results showed a greater impact in Mediterranean (+ 21.8% for total mortality) than in North Continental (+ 12.4%) cities. The highest effect was observed for respiratory diseases and among women aged 75-84 years. Air quality may also attribute to the additional deaths during heat waves. In the Netherlands Fisher et al. (2004) suggest that a significant proportion of the deaths now being attributed to the hot summer weather of 2003 can reasonably be expected to have been caused by air pollution. It is assumed that populations will slowly acclimatize to higher temperatures. Dessai (2003) assumes that it takes three decades to acclimatize to 1°C temperature rise.

A European heat wave occurred during the summer of 2003. Between 22,000 and 35,000 mainly elderly people, of which 14,802 died within 20 days. The associated costs of this heat wave were estimated at 13 billion Euro (Kovats and Hayat, 2008 and van Aalst, 2006).

Within the PESETA project (Ciscar, 2009) impacts of climate change at heat and cold related deaths are modelled. The main conclusion is that as a result of climate change the premature mortality related to heat is lower than the decreased mortality related to cold in 2020. In 2020 the potential increase in heat related mortality could be over 25000 premature deaths a year on an assumed population of 500 million. In 2080 this will increase further up to 50000 - 165000 deaths a year. If acclimatisation is taken into account the impact is significantly lower under the A2 scenario. 4000 premature deaths/year are projected around 2020and between 20000 – 60000 premature deaths/year in 2080. Under the B2 scenario acclimatisation exceeds the rate of climate change and premature deaths fall to zero. Relatively high increases occur in south and central Europe. The economic impacts in 2020 of premature heat related deaths are valued within the PESETA project between 13 -30 billion Euros and between 2 – 4 billion Euros with acclimatisation. By 2100 under the A2 scenario the economic impact ranges from 50 – 180 billion Euros.

National heat wave plans can contribute to limit the impact of heat waves. It is believed that these plans have largely contributed to the successful management and mitigation of the European heat wave of 2006 (Kovats and Hajat, 2008)

In 2020 the reduced mortality related to extreme low temperatures is projected to fall with 50,000 – 100,000 deaths/year. And in 2080 the reduced mortality in Europe is between 100,000 – 250,000 deaths/year. Acclimatisation is not taken into account because not enough information is available. The Baltic and Scandinavian countries are projected to have the highest fall. The smallest benefits are found in Ireland, Luxembourg and some Mediterranean countries. The economic benefits are valued between 23 – 110 billion Euros in 2020.

Due to the high uncertainty it is inappropriate to present these figures as net figures. However they give indications of the impact of climate change on the heat and cold related deaths in Europe. In the analyses exclude additional effects from heat waves, urban heat island effect and other temperature-related health effects.

Vector borne diseases

Vector-borne diseases are infections that are spread by insect vectors (Hunter, 2003). Climate change effects the distribution and survival of vectors, pathogen and hosts. This may result in changes in their geographic ranges, seasons of activity and population sizes. The effect will differ for every disease. The movements northwards and towards higher altitudes have already been observed. A simple correlation between vector diseases and climate change is not possible, because many other factors alter vector distribution, such as increasing globalisation, changes in water management, changes in human behaviour and changes in the health infrastructure. Important vectors are mosquitoes and ticks. Detailed information on different vector borne diseases has been summarized within the RESPONSE project (Hunter et al, 2010). Information on the West Nile Fever (WNF), Dengue fever, Chikungunya fever, Malaria, Leishmaniasis, TBE, Lyme disease, Crimean-Congo haemorrhagic fever, Spotted fever Rickettsioses, Yellow Fever and Rift Valley Fever can be found in the scooping document on health. We summarize the conclusions on these diseases:

- West Nile fever (WNF) (Culex spp mosquito): WNF outbreaks in France and Romania were associated with mild winters, dry springs and summers and eat waves early in the season (Semenza and Menne 2009).
- Dengue (Aedes aegypti mosquito and Aedes albopictus mosquito): Based on climate change projections it is predicted that Dengue distribution would shift northwards in Europe and up the mountain. Dengue is frequently reintroduced in Europe by travellers. Increased temperatures increase the risk of vector establishment at new locations and may increase the length of the transmission season (Hunter et al, 2010)
- Malaria (P. falsiparum, P. vivax, P.ovale, p. malariea): Climate change models estimate a potential increase on malaria, but there is agreement that in Europe the risks are very small because the high standards of health care services and management of mosquito control (Hunter, 2010).
- Yellow fever (A. aegypti, A. Albopictus): The treat of reintroducing yellow fever in Europe is trivial, because of an existing vaccine (Semenza and Menne, 2009)
- Tick borne encephalitis (Ixodes ticks): The expanding distribution of the vector from eastern and central Europe towards Scandinavia, Germany and Czech Republic where related to higher temperatures (Hunter, 2010)
- Lyme disease (I. ricunes and I. persulcatus): Milder winters may enable the tick distribution to move northwards. In the Netherlands the Lyme disease infections increased dramatically. Partly this is related to higher temperatures and milder winters. Therefore the Lyme disease is mentioned as one of the main risks for vector borne disease in Europe (Kovats et al, 2003). Other factors such as increased recreation also play an important role in the increase of infections.

- Leishmaniasis (sandflies): Similarly, the vector-borne disease leishmaniasis, transmitted by sandflies, has been reported in vector hosts further north, and there are reports of changes in the geographical distribution of the sandfly vector (EU commission 2009)

The characteristics of the European health care are expected to limit the risks of introducing vector borne diseases in Europe.

Water borne diseases

The link between water quality and health is strong. The main risks for Europe involve faecally polluted drinking and swimming water, cholera and risks of cyanobacteria. In Europe even in very severe droughts enough water is expected to be available for people's basis requirements (Hunter, 2010). Low income countries are more sensitive to droughts.

Faecally polluted drinking and swimming water poses risk to human health, especially young children. According to Senhorst and Zwolsman (2005) the effect of climate change on water quality is not clear. However outbreaks of waterborne diseases are often preceded by heavy rains. This risk posed to drinking water is limited to systems with inadequate water systems (Hunter et al, 2010). In swimming water climate change can influence concentration of faecals and the risks on getting the disease. As written above intensive rainfall increases the concentration. Sunlight has a disinfecting effect on faecally infected water

Cholera is considered an imported disease in Europe. Many studies point out the link between Cholera and climate variables, especially higher temperatures and rainfall levels, out brakes after floods and the relation with climatic cycles as El Nino (Hunter 2010).

Higher water temperatures are linked to an increased risk on the occurrence of harmful algal blooms. Cyanobacteria blooms limit water intake and recreation water use. The risks of cyanobacteria blooms are also increased by high nutrient levels and dry periods.

Extreme weather events and public health

Extreme events are rare events that can cause severe health problems. In Europe climate related extreme events are heat waves, cold spells, droughts, floods, fires and storms. Heat waves and cold spells are described earlier. Extreme events as floods, droughts, storms and fires have a direct effect on human health (casualties and injuries) but also an indirect effect. The indirect effect is an increased vulnerability to diseases and shortages of food and drinking water, caused by damaged infrastructure.

The effect of climate change on the frequency and fierceness of floods is described in the water section. Floods can cause injuries and death. A study by Jonkman and Kelman (2005) shows that two thirds of the deaths worldwide are from drowning and one third is from indirect effects, such as physical trauma, heart attack and electrocution. Long term health effects of floods are mental illness and infectious diseases. Several population groups are more vulnerable for floods (elderly, poor physical condition, poor, ethnic minorities)

In Europa the most significant health threat as a result of droughts is related to an increase of water availability and quality. Decreases in water flows lead to an increase of poor water quality health risks. These are described in the water borne diseases section. Droughts and water scarcity can increase demographic pressures, such as food insecurity and the agricultural system. Farmers may suffer from droughts and economic stresses can result in higher suicide rates among farmers.

Forest fires can have a large effect on human health. The direct effects can result in deaths among humans and animals, damages to crops property and infrastructure and a decrease of air quality. The reduced air quality may lead to an acute or a chronic negative effect on the functioning of the lung system. The risks on fires are directly linked to drier climates and the occurrence of droughts.

Although recent studies show that climate change might alter the frequency and the severity of storms. There is currently no evidence that storms have a significant effect on human health within the European Union.

Air quality

Poor air quality can cause respiratory diseases and is influenced by climate change in terms of distribution and concentration of pollutants. The relation between climate and respiratory diseases is complex and region specific (climate and population characteristics). Respiratory diseases are influenced by climate change through:

- Altered spatial and temperate distribution of allergens
- Increased level of respiratory and cardio events caused by ground level ozone and particulate matter
- Changes in frequency of respiratory diseases caused by long term air pollution (Ares et al, 2011).

The main concerns however are with chronically respiratory diseases as Asthma and chronic obstructive pulmonary disease (COPD) and acute respiratory infections. Ozone and particulate matter are the main pollutants (PM) that causes cardio respiratory diseases. Ground level Ozone is not emitted directly but originates from chemical processes in the atmosphere. Ozone and PM levels increase during warm summers. Ozone levels are already higher in Southern Europe than in Central and Northern Europe. There is evidence that both intensity and frequency of Ozone episodes may be increased by changing climate (WHO, 2010) an increase of health risks and an increased risk in mortality was observed in several epidemiological studies. The risk of mortality during heat waves is greater on days with high level Ozone and PM (WHO, 2010). Dry periods may lead to a reduced uptake of Ozone by plants. PM will rise as a result of increasing emissions and subsequently the level of Ozone will rise (WHO 2010).

Climate change can influence allergic disorders by lengthening the pollen season, altering the distribution of pollen producing plants, increasing pollen amounts and pollen allergenicity (WHO, 2010). There is good evidence that climate change led to earlier pollen production by plants. The health costs of pollen allergy are high.

Social economic drivers

The relation between human health and climate change are complex and interact with several other factors. Important factors are the population health status, population demographics and the health infrastructure. Vulnerable groups among are children, elderly, low income groups and people with health issues (WHO, 2010). In many parts of Europe population is aging.

In Europe the quality of health care is generally high. The WHO regional office for Europe concludes that health services play an important role in identifying, raising awareness advocating and adapting to climate change.

5.10.3 Damage and adaptation costs

Table 5.28: Damage costs Health

	2025		2080	
Sectors	**Estimated Damage Costs**	**Sources for Damage Estimates**	**Estimated Damage Costs**	**Sources for Damage Estimates**
Health	Negative to Low	Nordhaus Boyer 2000; Tol 2002	Negative to Low	Bosello et al 2009; Tol 2002

Table 5.29: Adaptation costs Health

Sectors	Themes	Adaptation costs (qualitative)	Sources	Notes
Health	Summer heat and winter cold related deaths	Low (2030, 2010-2050, 2060s)	Bosello et al 2009, World Bank 2009, Ebi 2008, Agrawala et al 2010	Global cost assessments consider Europe not as vulnerable. Negative adaptation costs possible (less morbidity costs due to warmer climate).
	Vector borne diseases			
	Water borne diseases			
	Air quality			

5.10.4 Summary

Summarizing main problems

Heath related deaths and air pollution are expected to have a big impact on the European health by 2020. The impact by 2080 is more uncertain. This problem might be more severe in cities. Problems with allergens are expected to increase. The treatment is related to high medical costs. The level of the European health care is important to reduce the risk of introduction of vector borne diseases. Lyme disease is mentioned as one of the main risks. Extreme events as fires, droughts and floods will have major direct and indirect health effects in the affected area. To limit the risks of these extreme events is important

Knowledge gaps

The vulnerability of cities has not yet been investigated properly. Cities might be more vulnerable because of the high population densities, the urban heath island effect and the air quality. On the other hand the health care system might be better in cities. At the moment there is not enough insight in the impact of climate change on European health, due to the complex interactions with other factors. As a result the effectiveness of adaptation measures has not yet been investigated properly. The economic impact of health risks is not included in most of the adaptation literature.

Table 5.30: Summary table Health

Climatic driver or social economic driver	Sub-threat or opportunity	Time-frame	Area affected1	Potential environmental impacts3	Potential economic impacts3	Potential social impacts3	Level of agreement and evidence2	Reference
Heat related deaths	Temperature Rise and heat waves	From 2020 it can be an important problem. It is uncertain how this will develop in the future, because of the role of acclimatisation and the uncertainty of the progress of the rise of temperature	Europe, but the most severe in southern and central Europe	Not available	With acclimatisation 2020: 2 – 4 billion 2080: 8-80 billion Without acclimatisation 2020: 13 – 30 billion 2080: 50 - 180 billion	Premature deaths on a population of 500 million With acclimatisation 2020: 4.000 2080: 0 – 70.000 Without acclimatisation 2020: 25.000 2080: 50.000 – 160.000	Medium/high, numbers are uncertain	Ciscar, et al. (2009)
Cold related deaths	Temperature Rise and cold spells	From 2020 an important benefit	Europe, but the north benefits the most. Small benefits in southern Europe	Not available	Benefits 2020: 23 -110 billion 2080:	Fall of deaths on a population of 500 million 2020: 50.000 – 100.000 2080: 100.000 – 250.000 Acclimatisation is not taken into account	Medium/high, numbers are uncertain	Ciscar, et al. (2009)
Vector borne diseases	Temperature, changing precipitation patterns (etc.) change the distribution, seasons of activity and	From 2020	Europe, but southern Europe has higher chances of (re)introduction, which already	Not available	Not available	Low because the general high characteristics of the European health care are expected to limit the risks of introducing	High/high	Hunter et al, 2010 Semanza and Menne, 2009 Kovats et al,

Climatic driver or social economic driver	Sub-threat or opportunity	Time-frame	Area affected1	Potential environmental impacts3	Potential economic impacts3	Potential social impacts3	Level of agreement and evidence2	Reference
	population size (differs for every disease)		occur			vector borne diseases. The Lyme disease is mentioned as one of the main risks for Europe		2003 EU Commision, 2009
Water borne diseases	Temperature rise, higher water temperatures, droughts and extreme rain events		Areas with inadequate water systems Throughout Europe for swimming water	Decrease of water quality	Not available	risks on faecially polluted drinking and swimming water, cholera and Cyanobacteria	High/high	Senhorst and Zwolsman (2005) Hunter (2010)
Health related risks floods	Extreme rainfall and sea level rise	See water section	See water section	See water section	See water section	Direct impacts through deaths and injuries Indirect impacts through physical trauma, heart attack and electrocution. Long term mental illness and infectious diseases (see water section)	See water section	Jonkman and Kelman, 2005
Health related risks fires	Droughts and heat waves	See soil and land use section	See soil and land use section	See soil and land use section	See soil and land use section	Direct impacts through deaths and loses (food and property) and a chronic reduction of the lung function	See soil and land use section	See soil and land use section
Air quality, allergens	Temperature rise, changing precipitation and wind patterns lead to	From 2020	Europe	Not available	Health costs are high	Not available	Medium/high	WHO, 2010

Climatic driver or social economic driver	Sub-threat or opportunity	Time-frame	Area affected1	Potential environmental impacts3	Potential economic impacts3	Potential social impacts3	Level of agreement and evidence2	Reference
	an altered spatial and temporal pattern of allergens and to increased allergenicity							
Air quality, pollution	Temperature rise and heat waves increase ground ozone and main pollutant levels in the atmosphere	From 2020, both frequency as intensity will increase	Complex and region specific. This depends on climate and population characteristics. But cities and southern Europe are expected to be vulnerable	Not available	Air quality is negatively influenced by emissions	Increased respiratory and cardio events and diseases	High/high	Ares et al, 2011 WHO, 2010

5.11 Coastal areas

5.11.1 Scenarios

For coastal zones, important scenarios are those for sea level rise which are derived from earth system modelling. Using the DIVA model, the PESETA project analyzed coastal flooding impacts (area, people, and costs, see Figure 17 for an example) for the set of A2 and B2 climate and sea level rise scenarios reported in IPCC's 3rd Assessment report (Richards and Nicholls, 2009). These results together with other literature and country reports formed the core of a broader economic analysis of coastal zone expenditures by PRC (2010, summary in EC, 2009a), which covered flooding, erosion, loss of eco-systems and freshwater shortage, and took into account an accelerated climate change according to the IPCC's 4th Assessment report. The study diversifies its findings to include the Baltic sea, the North Sea, the Atlantic, the Mediterranean, the Black Sea and the outermost regions. As noted in Hinkel et al. (2010), the IPCC AR4 gives a conservative range, and also notes that no reasonable upper bound of sea-level rise can be determined as we are unsure how rapidly the major ice sheets (Greenland and Antarctica) could collapse in a warming world. Several post-AR4 papers support the view that a 1 m+ rise in sea level over the next century cannot be discounted at present. These new insights about which no scientific consensus exists affect the estimates of the long-term risks for Europe's coasts.

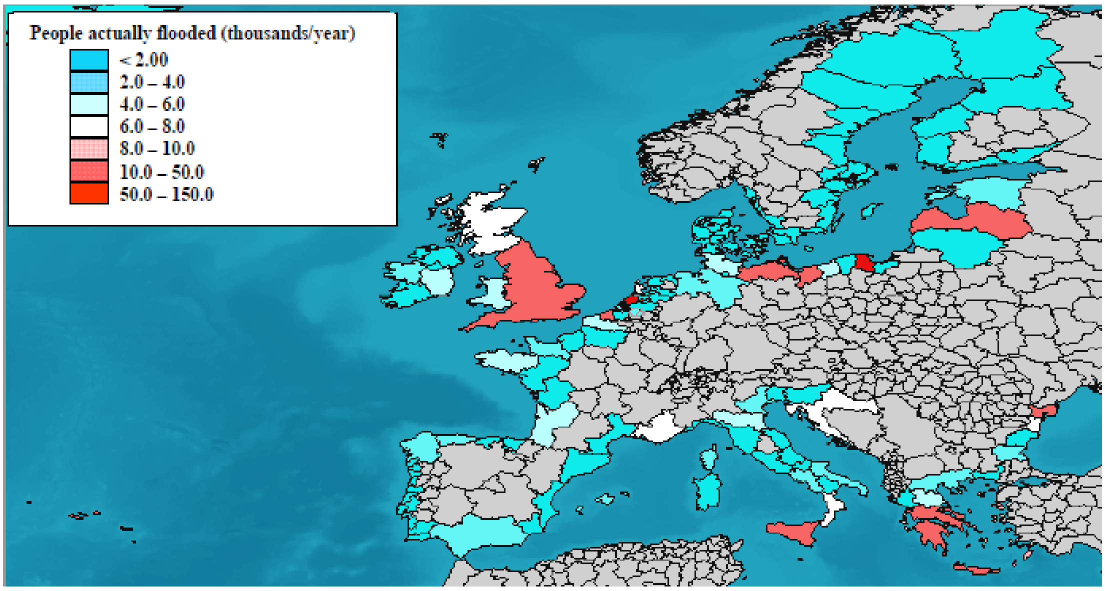


Figure 17: People actually flooded (thousands/year) across Europe, for the A2 scenario, 2080s (ECHAM4), without adaptation (Richards and Nicholls, 2009)

5.11.2 Literature assessment on impacts

Introduction

Climate change can have different impacts on the coastal zones of Europe, such as sea level rise, changes in storminess, salt water intrusion into deltas, estuaries and coastal aquifers, and coastal erosion. The most important effect is sea-level rise (SLR).

European legislation

To enhance more sustainable coastal development in Europe, the European Parliament and the Council adopted a Recommendation on Integrated Coastal Zone Management (ICZM) in 2002. It defines the principles of sound coastal planning and management, including the need to take a long-term and cross-sector perspective, to pro-actively involve stakeholders and the need to take into account both the terrestrial and the marine components of the coastal zone. Right now the EU ICZM Recommendation is under review and the options for future EU action are assessed. To complement the efforts by EU coastal Member States and regions to implement the EU ICZM Recommendation, the European Commission launched the OURCOAST initiative. OURCOAST gathers and disseminates case-studies and practical examples of coastal management practice in Europe.

In 2010, the EU strengthened the legal framework for integrated coastal zone management in the Mediterranean by deciding to ratify the ICZM Protocol to the Barcelona Convention.

Sea level rise

In the most comprehensive coastal vulnerability assessment for the fourth IPCC report (Solomon, 2008), a range between 18 and 59 cm sea level rise has been considered. After its publication, a number of studies indicated that the upper bound could be underestimated and could be up to 2 m, although this high impact value is considered to have very low probability (see e.g., Nichols et al., 2011 for a review).

For the European seas adjacent to the Atlantic Ocean the global mean SLR could give a reasonable approximation of the expected changes, although for the coastal zone a number of other factors, like land subsidence, fluid extraction and coastal erosion will yield very differently relative to sea level.

The cascading Mediterranean and Black seas, connected with each other and the Atlantic ocean via narrow straits will have different patterns of sea level change than the global mean, especial if global mean changes happen according to the lower bound of the projections. Today, the Mediterranean Sea level is slightly increasing and the sea level in the Black Sea is rising faster than the global mean. The reasons for this distinct behaviour are different for each of these seas. The Mediterranean Sea is a concentration basin and there evaporation greatly exceeds influx of fresh water from precipitation and river runoff. These processes could cause a time lag of sea level rise in the Mediterranean of a few decades (Tsimplis et al., 2006). For the nearly enclosed Black Sea, connected to the Mediterranean Sea by the narrow Bosporus Strait, this time lag will be even larger. For the medium-upper bound of the projections regional sea level in the Mediterranean is expected to harmonize with the global trend (Vellinga et al., 2011). There are no regional SLR projections for the Black sea yet.

Sea level rise will have severe economic and environmental impacts on the coastal system. Significant populations are threatened by flooding and erosion. Adaptation is expected to reduce the impact significantly (Richard and Nicholls 2009) As a result of sea level rise the coastal ecosystems will significantly be reduced, especially under high sea level rise scenario's (Richard and Nicholls 2009).

Storm surges

Another impact of warming climate on coastal zones could be a change in extreme storm surges. For most of the European coasts the projections suggest no significant increase of storm surge intensity; the projected changes are within the observable range of natural variability (e.g., von Storch and Woth, 2008, Lowe et al, 2009, Lionello et al., 2010).

Coastal flooding and salt water intrusion

The PESETA coastal report (Richards and Nichols, 2009) uses the DIVA model to assess European coastal vulnerability to sea-level rise. The model is driven by sea level and socio-economic scenarios and includes important coastal processes such as coastal erosion, coastal flooding (also from river side), salinity intrusion into deltas and estuaries and changes of wetlands. It also allows to include adaptation measures, although in a very simplified way: for the PESETA study the only two measures considered are dike construction and beach nourishment. The projections of PESETA suggest that by 2085 between 775,000 and 5.5 million people in the coastal zone could be flooded annually without adaptation (for the reference year 1995 this number is 36,000). As very vulnerable areas are identified the British Isles, the Central Europe North and Southern Europe regions. If adaptation measures are taken, under B2 the number of people flooded peaks at 2050s and then decreases to the levels reached in 2020s, while under the A2 scenario it does not change as the increased level of protection is compensated by increased population leaving in vulnerable area. The land loss due to annually flooded areas and erosion as percentage of the region total without adaptation is between 0.2% (for Northern Europe) and 1.5% (for the British Isles), or about 0.6% as European average for the A2 scenario. Sea floods could result in losses of about 6020.4 million euro/year, salt intrusion at about 607.5 million euro /year, and migration - 0.3 million e/year in 2020s under this scenario and no adaptation. For 2080 these numbers are 18242.5 and 1053.3 and 25242.6 million euro /year respectively. The A2 scenario, combined with "optimal adaptation" does not change the numbers for salt water intrusion and migration 2020s considerably – they are 607 mln euro /year and 0.2 mln euro/year respectively. The losses due to sea floods decrease to about 1116 mln euro/year. The adaptation costs in these scenarios are 1013 mln. Euro/year and net benefit of adaptation 3896 mln. Euro/year in 2020. In 2080 the damage costs are estimated at 1159.3, 1053.3 and 20.1 million euro/year respectively for sea floods, salt intrusion and migration for the A2 scenario and optimal adaptation. The adaptation costs in 2080 are 2607 mln. Euro/year, while the net benefit of adaptation is 39756 mln. Euro/year.

The Climate cost project assessed the potential economic impact of climate change in Europe's coastal zones, using the DIVA model. Projections under a medium to high emission scenario (A1B) give a 37 cm sea level rise for Europe in the 2080s. With no mitigation and adaptation, under the A1B scenario annually an additional 55,000 people could be affected by coastal flooding in the EU in the 2050s and more than 250,000 people by the 2080s. Taking into account an ice-melt related uncertainty range, the 5-95 % uncertainty range would be between about 120,000 to more than 400,000 additional people at risk by the 2080s. . The annual undiscounted economic damage costs are estimated up to about 11 billion Euro by 2050, rising to more than 25 billion Euro by 2080 (socio-economic and climate changes taken together). The marginal effects of climate change alone would amount to 2.4 B€/yr. by the 2020s, about 6 B€/yr. by the 2050s and more than 18 B€/yr. in the 2080s. Under a high sea level rise scenario (1.2 m), the marginal climate effects could rise to almost 150 B€/yr. in the 2080s. The analysis also shows also a huge impact on the European wetlands, which has not been valued in economic terms. Estimates suggest that by 2080 over 35 percent of the European wetlands might be lost, unless protected measures are taken (Brown et al, 2011). Under an E1 emissions scenario, which is broadly consistent with a 2 °C temperature rise scenario, a 27 cm sea level rise for Europe is projected. Under this scenario about 45,000 to 145,000 people are projected to be at risk of flooding by the 2080s and the undiscounted damage costs in these years are estimated at about 17 billion Euro/year (Brown et al. 2011). The uncertainties for this type of estimations are high, for example, the annual undiscounted damage costs associated with a higher, 1.2 meter sea level rise are 156 million Euro for Europe (Brown et al, 2011). It should also be noted that the estimated damages only consider direct effects of coastal flooding and not secondary, indirect economic costs. Protection levels at the national level can be higher (e.g., in The Netherlands) or lower (e.g., Black Sea countries) than assumed in the model.

The Climate cost project also assessed the costs and benefits of adaptation for sea level rise, considering beach nourishment and dikes. Adaptation greatly reduces the overall cost of flood damage. The annual cost of adaptation is estimated at 1.5 billion Euro in the 2050s and 1.6 B€ in the 2080s (A1B) for socio-economic and climate changes taken together, which would be reduced to 1.1 and 1.2 B€/yr. for E1, for the 2050s and 2080s, respectively, and achieves a benefit to cost ratio of 1:6 (Brown et al. 2011). The uncertainties are high and depend strongly on the level of future climate change, the level of accepted protection and the framework of analyses (Brown et al. 2011).

Hinkel et al, (2010) assessed the impact of sea level rise under an A1 and B2 scenario. In 2100 assuming no adaptation, 780,000 people (A2) or 200,000 (B1) people are estimated to be affected by coastal flooding. Under both scenarios the associated costs are roughly 17 billion USD.

Tol (2002) performed estimations for the damage costs of floods. He based his calculations on studies by Bijlsma et al. 1996, Hoozemans et al. 1993, and Frankhauser (1994)). He estimated that a 1 meter sea level rise leads to a yearly cost of 1.7 billion USD for OECD-Europe and 0.5 billion USD for Central Europe and the former Soviet union.

Social economic drivers

Population density and economic value are important to determine the impact of sea level rise. While worldwide, the increase in coastal population appears to exceed the average population growth, no scenarios have been found that confirm this trend for Europe. Migration scenarios focus on international migration from other regions and internally in the EU from east to west (e.g., Bijak et al., 2004) but not on internal migration to coastal zones. The population of Europe is not expected to grow. For Europe a birth rate of 1.6 children per woman is expected whereas the population replacement level is 2.1. It is not clear if immigration can compensate for the birth declines. (http://europa.eu/legislation_summaries/employment_and_social_policy/situation_in_europe/c10160_en.htm).

5.11.3 Damage and adaptation costs

Table 5.31: Damage costs Coastal areas

	2025		2080	
Sectors	**Estimated Damage Costs**	**Sources for Damage Estimates**	**Estimated Damage Costs**	**Sources for Damage Estimates**
Coastal areas	Low to Medium	Nordhaus Boyer 2000; Mendelsohn et al 2000	High	Stern Review; Tol 2002; PESETA

Table 5.32: Adaptation costs Coastal areas

Sectors	Themes	Adaptation costs (qualitative)	Sources	Notes
Coastal areas	Not available yet	High (2030, 2060s, 2080s)		See sector Water

5.11.4 Summary

Summarizing main problems

Most important impacts are coastal flooding, coastal erosion and salt water intrusion due to sea level rise.

Knowledge gaps

There are no sea level projections for the Black Sea.

Table: 5.33 Summary table Coastal areas

Climatic driver or social economic driver	Sub-threat or *opportunity*	Time-frame	Area affected[1]	Potential environmental impacts[3]	Potential economic impacts[3]	Potential social impacts[3]	Level of agreement and evidence	Reference
Temperature, ice sheet melting	Sea Level Rise	2020	British Isles, the Central Europe North and Southern Europe regions	n.a.	Losses due to sea floods of about 6020.4 mln euro/year, due to salt intrusion at about 607.5 mln euro /year, to migration 0.3 mln euro/year in A2 scenario and no adaptation Losses due to sea floods of about 1116 mln euro/year, due to salt intrusion at about 607 mln euro /year, to migration 0.2 mln euro/year in A2 scenario and optimal adaptation. Adaptation costs 1013 mln. euro/year, net benefit of adaptation 3896 mln. euro/year		medium	PESETA
Temperature, ice sheet melting	Sea Level Rise	2050	British Isles, the Central Europe North and Southern Europe regions	n.a.	Land Loss: 0.2% (for the Northern Europe) ,1.5% (for the British Isles), about 0.6% as European average for A2 scenario		medium	PESETA
Temperature, ice sheet melting	SLR	2085	British Isles, the Central Europe North and Southern Europe regions		Losses due to sea floods of about 18242.5 mln euro/year, due to salt intrusion at about 1053.3 mln euro /year, due to migration 25242.6 mln euro/year in A2 scenario and no adaptation Losses due to sea floods of about 1159 mln euro/year, due to salt intrusion at about 1053 mln euro /year, due to migration 20 mln euro/year in A2 scenario and optimal adaptation	Between 775,000 (B2 scenario, 8 cm SLR) and 5.5 mln (A2 scenario, 88 cm SLR) flooded	medium	PESETA

Climatic driver or social economic driver	Sub-threat or *opportunity*	Time-frame	Area affected[1]	Potential environmental impacts[3]	Potential economic impacts[3]	Potential social impacts[3]	Level of agreement and evidence	Reference
					Adaptation costs 2607 mln. euro/year, net benefit of adaptation 39756 mln. euro/year			
Temperature, ice sheet melting	Sea level rise	2050 (A1B-scenario)	EU		11 billion euro/year	55,000 people annually flooded	Low	Climate cost, Brown et al 2011
Temperature, ice sheet melting	Sea level rise	2080 (A1B-scenario)	EU	35% wetland loss	25 billion euro/year	250,000 people annually flooded	Low	Climate cost, Brown et al 2011
Temperature, ice sheet melting	Sea level rise	2080 (E1-scenario)	EU		18 billion euro/year	180,000 people annually flooded	Low	Climate cost, Brown et al 2011
Temperature, ice sheet melting	Sea level rise	2050 (A1B-scenario)	EU		1Adaptation costs (current prices undiscounted) 1.6 billion euro/year Benefit-to-cost raio 1:6		Low	Climate cost, Brown et al 2011
Temperature, ice sheet melting	Sea level rise	2100 (A2 and B1 scenario	EU		17 billion UDS/year	200,000 (B1) to 780,000 (A2) people annualy flooded	Low	Hinkel et al. 2010
Temperature, ice sheet melting	Sea level rise	1 meter	OECD-Europe Central and		OECD-Europe 1.7 billion UDD/year		Low	Tol 2002

Climatic driver or social economic driver	Sub-threat or *opportunity*	Time-frame	Area affected[1]	Potential environmental impacts[3]	Potential economic impacts[3]	Potential social impacts[3]	Level of agreement and evidence	Reference
			Eastern Europe and the former Soviet Union		CEE&fSU 0.5 billion USD/year			

5.12 Urban areas, buildings and telecom

5.12.1 Scenarios

While urban areas are not a specific EU-policy area, urban areas are specifically vulnerable because of the urban heat island effect, the possibility of flooding during high intensity rainfall events (and for coastal or river cities), and the dependence on external service provision (water, power, food). The PLUREL project focuses on new strategies and planning and forecasting tools that are essential for developing sustainable rural-urban land use relationships. In PLUREL, the IPCC and other scenarios have been used to analyze a number of developments relevant for urban areas, including demographic development (by age, gender). The project developed scenarios for urban land-use development in Europe, focusing on a number of case study regions (Reginster and Rounsevell, 2006; Petrov et al., 2006). PLUREL case studies focus on urban conflicts: land pressure due to housing, agricultural land under pressure, nature at risk, integration of tourism, traffic, water management. The IPCC scenarios are complemented by "shock" scenarios. The results are translated into maps (e.g. Rickebush, 2010; Rickebush et al., 2010).

The same focus on mitigation rather than on climate change impacts, vulnerability and adaptation holds for buildings. The EU Strategy for the sustainable competitiveness of the EU construction sector mentions climate change as an important challenge for the sector to meet. Ecorys (2011) notes that long term infrastructure will have to adapt to future climate risks and suggests to customize solutions regarding the Energy Performance Building Directive (EPBD) to climate zones. EMCC (2005a) describes four different scenarios for the future development and status of the European construction sector (The Lighthouse of Alexandria; The great wall; The tower of Babel; and The leaning tower of Pisa), analyzing various external and internal challenges for micro-companies, medium-to-large sized companies, SME knowledge intensive, and large international companies. This extensive scenario exercise explores different developments for ICT incorporation and labour market flexibility rather than environmental (or climate change) challenges.

As to telecommunication, vulnerability of communication networks are similar to those for power and transport networks (see energy and transport and infrastructure sections) – no specific scenarios have been identified in a climate change context. However, EMCC (2005b) describes four scenarios (a surprise-free reference scenario and three alternative scenarios: a disruptive scenario: Information society; a steadily progressive scenario, and a standstill scenario), none of which takes vulnerability of the transmission capabilities into account.

5.12.2 Literature assessment on impacts

Introduction

The expansion of built-up areas through suburbanisation is still growing in OECD metropolitan areas - 66 out of the 78 largest OECD cities experienced a faster growth of their suburban belt than their urban core over 1995-2005 (OECD, 2010). In many cases, suburban development, often encouraged by an increased emphasis on the free market and privatization and less controlled by governments as in the past, has taken place with little consideration to maintaining natural features that create buffers against floods or protect buildings against climatic events (Carmin and Zhang, 2009). In the PLUREL project, using the Regional Urban Growth model, an increase in artificial surface is projected, particularly in peri-urban areas, but in general no quantitative estimates could be identified for these non-climate factors. It can be expected that without changed policies, these trends will increase exposure and sensitivity (living, building and investing in flood-prone areas). At the same time, economic development and awareness of urban vulnerability is likely to increase adaptive capacity. Since urban design and buildings typically last for decades or more, the design of new urban developments offers the greatest opportunity to limit vulnerability.

European legislation

The Thematic Strategy on the Urban Environment (EC, 2006) notes that urban areas are vulnerable to the consequences of climate change such as flooding, heat waves, more frequent and severe water shortages and that integrated urban management plans should incorporate measures to limit environmental risk to enable urban areas to deal better with such changes. Guidance in relation to the Thematic Strategy on the Urban Environment focusing on Integrated Environmental Management suggests that cohesion policy can play a major role in addressing climate change risks (EC, 2007). However, a few years later the European Commission still notes that cohesion policy should address the climate change challenge, but does not consider yet how this can be done (EC, 2010). At the same time, it should be noted that many cities in Europe have started to assess their vulnerability to climate change and develop adaptation strategies, often as a component of a broader climate strategy that primarily targets climate change mitigation (Ribeiro et al., 2009; Ecologic, 2011).

For buildings, the ten EN Eurocodes are a series European Standards, providing a common approach for the design of buildings and other civil engineering works and construction products. They aim at eliminating the disparities that hinder free circulation within the Community, are meant to lead to more uniform levels of safety in construction in Europe, and are designed to become the reference design codes replacing national codes. They cover earthquake resistance, but not yet climate proofing. The EU Strategy for the sustainable competitiveness of the EU construction sector mentions climate change as an important challenge for the sector to meet. Ecorys (2011) notes that long term infrastructure will have to adapt to future climate risks and suggests to customize solutions regarding the Energy Performance Building Directive (EPBD) to climate zones. The EU Energy Performance of Building Directive allows member states to comply with the Kyoto protocol.

In the area of telecommunication, the eTEN (Trans European Telecommunications Networks) programme finished at the end of 2006. From 2007 onwards European Commission supports the electronic services in the areas of public interest through the ICT Policy Support Programme (ICT PSP), which will run until 2013 as a component of the Competitiveness and Innovation Framework Programme (CIP). Climate change is not yet taken into account in this area.

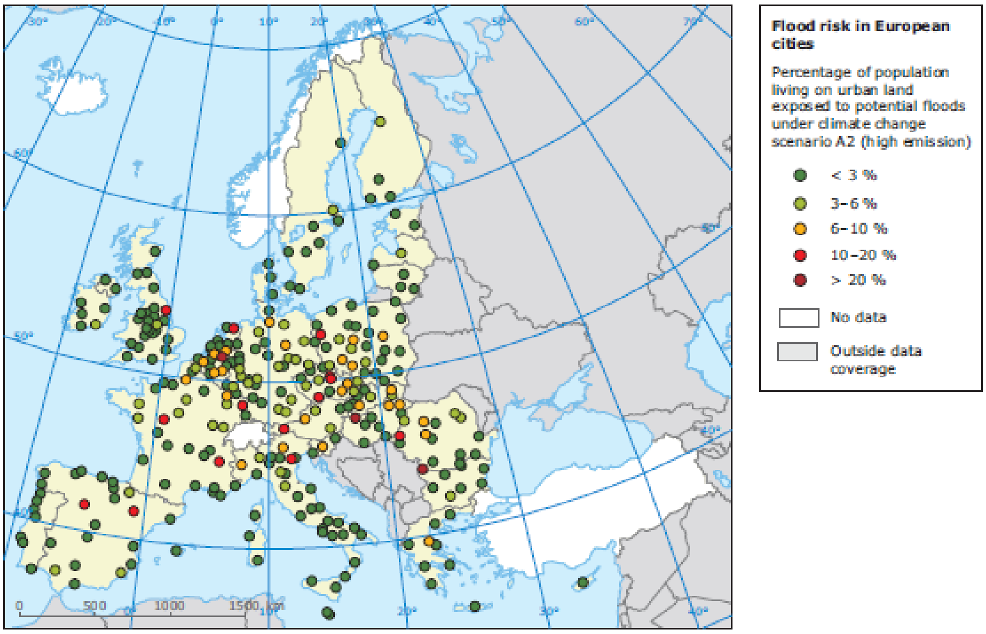
Urban areas

The vulnerability of urban areas to climate change has been the subject of various international assessments, most recently in a European context by the EEA (EEA, 2008, 2010a, 2010b). Climate change will affect urban areas directly in worsen existing urban problems, such as low air quality and poor water supply (Figure 18). Potential impacts of climate change on urban areas include (Dawson et al. 2009; Schauser et al, 2010; Robrecht et al., 2011):

- Problems related to extreme precipitation events (see Figure 1 for example):
  - Sea level rise and storm surge flooding,
  - Fluvial flooding,
  - Urban drainage flooding,
  - Building and infrastructure subsidence and landslides,
  - Wind storm.
- Heat- and health-related problems:
  - Heat and health (changing profile of heat vs. cold related deaths),
  - Diseases (changing profile of vector and water-borne diseases),
  - Air quality and health.
- Problems related to dependence on external services
  - Water scarcity , droughts and salt water intrusion and implications for water resources both in terms of quality (and concomitant implications for health and aquatic ecosystems) and availability for human consumption, industry and neighbouring agricultural areas,
  - Implication for energy supply (e.g. damage of the energy grid due to snow cover)
  - Resources and amenity (power, communication, other services)

The potential impacts are not evenly distributed across Europe: in southern Europe more heat waves, droughts, water scarcity and peri-urban forest fires (e.g. Athens); in central and eastern Europe: more droughts, heat waves and river floods; in northern Europe: more damages by winter storms and floods; in mountain areas: more natural hazards, including floods, avalanches and rock falls; and in coastal areas: sea level rise and increased frequency of storm surges (Schauser et al., 2010). The vulnerability of cities depends not only on potential climatic change, but also on the way urban areas are built. Urban design, and ultimately land cover and land use, can aggravate climate change impacts, for example through soil sealing contributing to the heat island effect (see Figure 19 for example) and flooding caused by water run-off. Temperatures can differ significantly across a city, with green areas being typically cooler than high-density urban areas, providing better ventilation and water storage potential (EEA, 2010a,b).

In this summary note, we do not elaborate on all these different impacts, but refer to the referenced literature. One exception we make for the impacts of climate change on air quality, about which little is known yet. In the US, a first systematic attempt was made to use linked global-to-regional climate and air quality modelling systems from multiple research groups to jointly investigate the regional dimensions of potential climate-induced air quality changes across the United States. The major findings was that the experiments demonstrate the potential for global climate change to make U.S. air quality management more difficult, and therefore future air quality management decisions should begin to account for the impacts of climate change, noting that the science of modelling climate and atmospheric chemistry for the purposes of understanding the sensitivity of regional air quality to climate change is in its early stages (USEPA, 2009). This suggests that also in Europe, climate change might make attainment of notably ozone goals more difficult to achieve, maintain, or strengthen in the future. In Europe, preliminary analysis is taking place (Anderson, 2009), and EEA (2009) notes the strong dependency of ozone levels on meteorology suggesting that predicted changes in climate could also lead to increased ground-level ozone concentrations in many regions of Europe.



Note: Per city, the population living in the Larger Urban Zone as described in the Urban Atlas/Urban Audit definition (GMES, 2010 and Eurostat, 2010) is considered. The calculation uses the population distribution on urban land-use classes from Corine land cover 2000. Furthermore, neither coastal floods nor flood protection measures are considered in the calculation. Based on the hydrological model LISFLOOD.

Sources: Dankers and Feyen, 2008; Dankers and Hiederer, 2008; Dankers, Feyen and Christensen, 2009; Gallego, 2010.

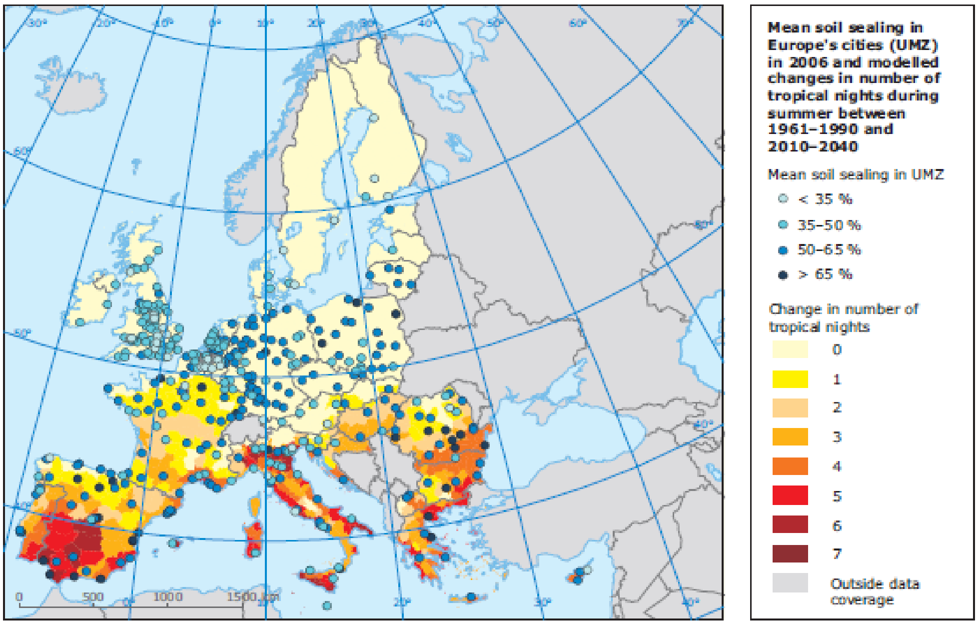
Figure 18: Exposure of population in European cities to flood risk under climate change (scenario A2 — high emissions; 100-years flood). Source: EEA, 2010a

Socio-economic developments affecting exposure, sensitivity and adaptive capacity

The vulnerability of urban areas is influenced by a number of non-climate factors, including high population density (concentrated vulnerability, overcrowding, social problems); urbanization and expansion (in-migration, pressure on services (e.g. health, police) and resources (e.g. utilities) and urban sprawl with pressure on surrounding ecosystems); increasing sealing (high run-off rates, high drainage load); traffic congestion and poor air quality; ageing infrastructure; social inequality; urban heat island effect; long, global supply chains and just-in-time delivery practices; dependence on electricity supply for most services and security; and pressure to de-carbonise urban settlements and economies (Ecologic, 2011). Most vulnerable groups to climate change include the elderly; low income groups; disabled or sick persons; the young; and ethnic or religious minorities, which are all important groups in urban areas. It should also be noted that vulnerability to pluvial floods depends largely on the maintenance of the storm water disposal system.

Buildings

Buildings can be vulnerable to climate change because of their design (low resistance to storms) or because of their location (e.g., in flood-prone areas, landslides, avalanches). In addition to structural strength, also comfort of occupants can be affected by climate change. Carmin and Zhang (2009) call attention to the preservation of historic buildings, monuments, and archives in the historically very rich European cities, for example because building facades as well as statues and other monuments can deteriorate as a consequence of exposure to salts, pollutants, and changing weather patterns.



Source: Dankers and Hiederer, 2008; EEA, 2010c.

Figure 19: Mean soil sealing in Europe's cities (UMZ) in 2006 and modelled change of number of tropical nights (Tmin > 20 °C) during summer between 1961–1990 and 2010–2040 indicating higher risks of heat waves. Source: EEA, 2010a

Telecom and energy supply

Also in the ICT community the emphasis is on mitigation. Nevertheless, like power systems also communication systems can be vulnerable to climate change, and to disruptions of power supply. No systematic assessment of ICT vulnerability is known. ICT can play an important role in climate change adaptation, e.g. through early warning systems in case of extreme events. The power grid can be affected by ice cover and snow storms leading to supply interruptions.

5.12.3 Damage and adaptation costs

Table 5.34: Damage costs urban areas, buildings and telecom

	2025		2080	
Sectors	**Estimated Damage Costs**	**Sources for Damage Estimates**	**Estimated Damage Costs**	**Sources for Damage Estimates**
Urban areas, buildings and telecom	High	Nordhaus Boyer 2000	High	Nordhaus Boyer 2000

Table 5.35: Damage costs urban areas, buildings and telecom

Sectors	Themes	Adaptation costs (qualitative)	Sources	Notes
Urban areas, buildings and telecom.	Flooding	High (2010-2050)	World Bank 2009	Low coverage for inland flood protection costs, See sector Water
	Building and housing Infrastructure	Potentially by far the highest (and uncertain) (2030, 2060s)	UNFCCC 2007, Bosello et al 2009, Agrawala et al 2010	High uncertainty range (e.g. 6-88 in USD / year UNFCCC 2007) – vulnerable proportion of new investment is estimated and the additional costs for climate-proofing this proportion.
	Health	Low (2030, 2010-2050, 2060s)		See sector Health
	Water resources	Medium (2030, 2060s, up to 2080)		See sector Water
	Telecom Energy, communication resources	High (2030, 2060s)		See "Infrastructure", no specific adaptation cost estimates for Telecom and communication. For Energy, see sector Energy.

5.12.4 Summary

Summarizing main problems

Most serious impacts seem firstly urban heat and air quality deterioration that combined can lead to higher number of deaths during heat waves; and secondly extreme events like flooding and disruption of power systems through wind storm damage.

Knowledge gaps

Little is known on the impacts of climate change on air quality. There is no info on ICT vulnerability to climate change; at the same time, ICT could play an important role in early warning systems.

Table 5.36: Summary table urban areas, buildings and telecommunication

Climatic driver or social economic driver	Sub-threat	Time-frame	Area affected[1]	Potential environmental impacts[3]	Potential economic impacts[3]	Potential social impacts[3]	Level of agreement and evidence[2]	References
Changing precipitation patterns	Fluvial/urban drainage flooding	2020	Cities on rivers	Pollution (waste dumps, gas stations)	Through physical damage	Water safety	Medium/low	Schauser et al., 2010
	Building and infrastructure subsidence and landslides	2050	Mountain areas	NA	Through physical damage	Safety	Medium/low	Infrastructure Canada, 2006
	Water scarcity, drought and implications for water resources	2020	Southern Europe	Aquatic ecosystem impacts	Economic activities constrained	Inconveniences b service disruption	Medium/medium	Schauser et al., 2010
Temperature increases	Heat/ cold related deaths	2050	Improving in NE, deteriorating in SE	NA	Decreased labour productivity	Health impacts	Medium/medium	EEA, 2010a, Ecorys, 2011
	Diseases (vector and water-borne diseases)	2050	Europe-wide	NA			Medium/low	EEA, 2010a
	Air quality and health	2020	Europe-wide, notably south	Ecosystem impacts			Medium/low	EEA, 2010a, Anderson, 2009
Sea level rise	Sea level rise and storm surge flooding Salt water intrusion	2080	Coastal cities	Pollution (waste dumps, gas stations)	Through physical damage	Water safety	Medium/low	Schauser et al., 2010
Extreme events (storms)	Direct wind storm damage	2080	Europe-wide, coastal areas	NA	Economic activities constrained	Inconveniences b service disruption	Low/low	Carmin and Zhang, 2009
	Disruption of power, communication, or other services	2050	Europe-wide, coastal areas	NA			Low/low	Carmin and Zhang, 2009

6 Discussion and summary of scenarios

Types of scenarios

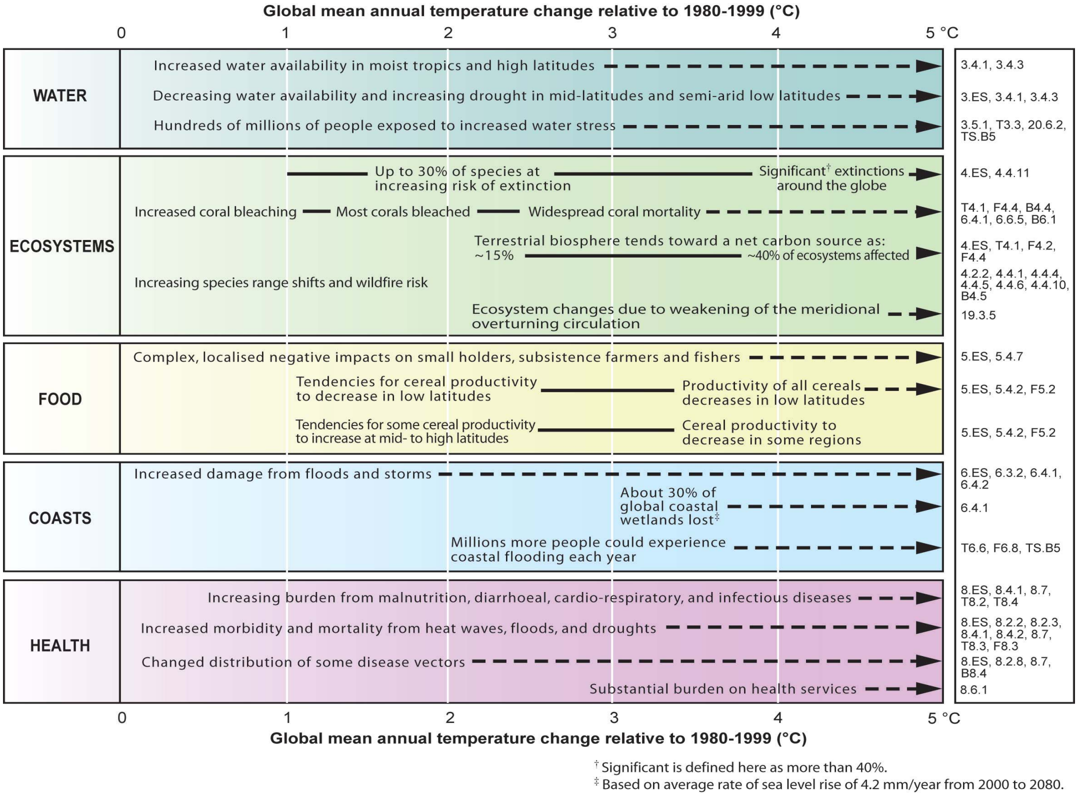
The inventory of scenario exercises for Europe shows that a number of distinct categories of scenarios can be distinguished (see also Table 3.1):

- Research- and model-based scenarios to evaluate long-term impacts of global change in general and climate change in particular. For Europe-wide analyses, these scenarios are often developed in the context of EU research projects. Over the last decade, they are mostly based on a selection of scenarios from the ENSEMBLES experiments, which use a selection of SRES scenario to determine the greenhouse gas forcing, or assume stabilization of GHG concentrations (E1). This selection is not harmonized, and therefore differs for different projects. Examples include ATEAM, ALARM, ADAM, EURURALIS, SEAMLESS, CEHAPIS.
- Scenarios on climate change impacts to support EU-policy development. In the context of the PESETA project, the selection of scenarios and GCM was better harmonized, leading to analysis of selected future climate impacts for agriculture, river flooding, coastal safety, health and tourism.
- Scenarios that explore long-term socio-economic driving forces in a climate change context. SCENES is the prime example of this category of scenarios, not only developing scenarios for water demand, but also relating this to supply as it is also influenced by climate change, e.g. in the context of the ClimWatAdapt project.
- Scenarios in support of sectoral strategies. For many policy areas, scenarios are used as a tool to explore future challenges for economic and technological development. They can focus on the short- to medium term (e.g., for agriculture, fisheries, forestry, tourism), or on the long term (e.g., some energy scenarios). They can be relevant for analyzing threats because they can affect exposure, sensitivity and adaptive capacity to climate change.

Usually, the scenarios cover a wide range of possible futures. The broadest consistent Europe-wide analysis in support of climate adaptation policy, PESETA, included two long-term scenarios, namely IPCC SRES B2 (low-medium) and A2 (high-medium). The PESETA analysis has been used to support the proposals in the EU White Paper on adaptation, by showing that Europe is vulnerable to climate change, based on projections for selected potential impacts for both B2 and A2 in the 2080s. The current project however is focusing on the climate resilience of EU policies, on both the short and long term.

Avoided impacts of a two degrees scenario

The residual impacts for Europe of a scenario in which the global average temperature would be limited to the EU policy target of 2 degrees have not yet been published. From the IPCC AR4 assessment some idea of impacts to be avoided can be derived. Figure 20a shows key impacts as a function of increasing global temperature change for key sectors, while Figure 20b shows the same for world regions (IPCC, 2007). For Europe, the figure confirms that even for a 2 degree change, both for water and agriculture impacts are projected, but they vary in a wide range with often different signs because of regional differences and scientific uncertainties. One could say that for some sectors, like agriculture, the residual impacts in a 2 degree world are probably less important than for other sectors (e.g., biodiversity), and hence climate change is a smaller threat in such a mitigation world.



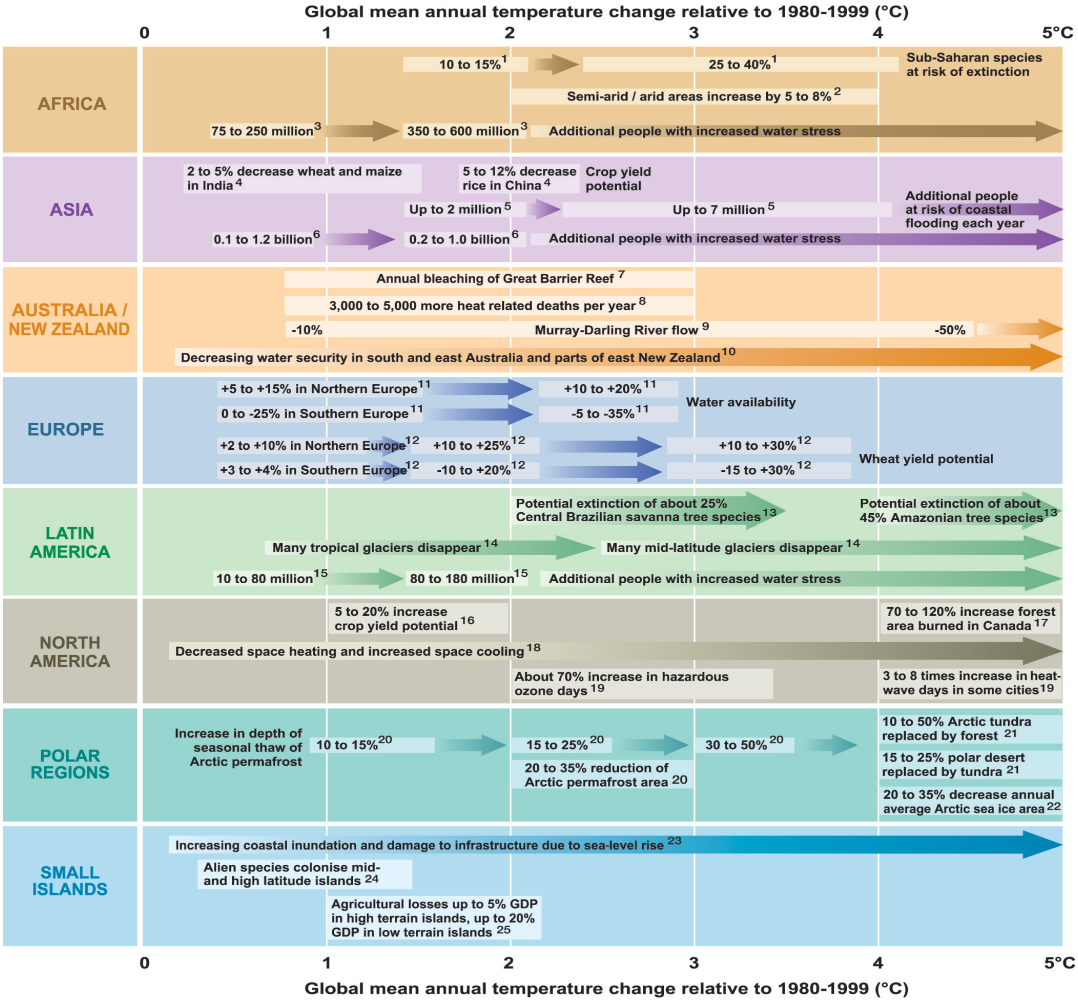


Figure 20a, b: Key impacts as a function of increasing global temperature change for (a) key sectors and (b) key regions (IPCC, 2007)

In ENSEMBLES, a scenario consistent with a 2 degree target has been developed (E1), but the consequences for impacts have not yet been systematically addressed. In the context of the ADAM project, an analysis of the potential avoided impacts at the global level has been performed (van Vuuren, in press). Van Vuuren et al. (unpublished) analysed water availability, impact on heating and cooling, malaria risks, agricultural (yield) impacts, and sea level rise for a high-adaptation needs scenario in which temperatures are expected to increase by about 4 degrees by the turn of the century, and a strong mitigation scenario in which there would be about 50 % chance that temperature would be limited to 2 degrees. They note that even under this scenario, substantial adaptation measures will be needed.

Projects like RESPONSES (to some extent a follow-up to ADAM) plan to further elaborate such analyses, but will not produce relevant results in 2011. However, it is important to note that in the coming decades, the projected ranges for changes in climate variables, particularly for precipitation and hence for impacts, are largely overlapping and hence avoided impacts can not be meaningfully quantified on short- to medium timescales. As illustrated in Figure 21, mitigation and adaptation can be regarded to serve different objectives: mitigation aims at reducing the long-term risks of climate change, while adaptation addresses potential impacts of climate change and climate vulnerability at short- to medium timescales and has immediate benefits.

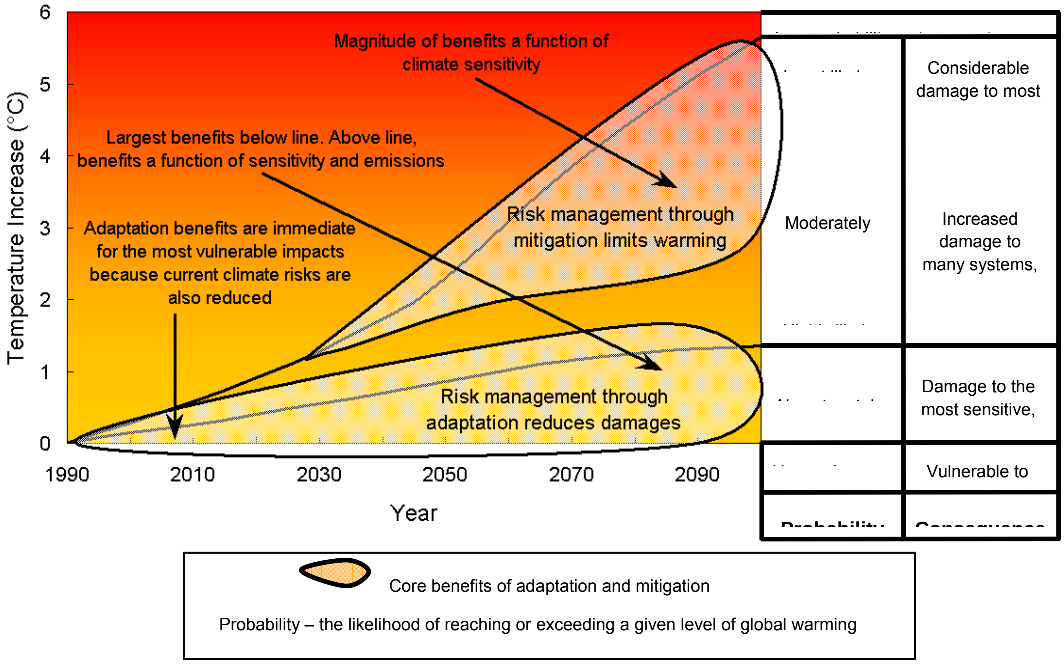


Figure 21: Mitigation and adaptation are complementary and serve different purposes (source: Roger Jones)

Beyond the White Paper assessment

To go beyond the analysis of the White Paper, we propose to elaborate two additional aspect of potential climate change impacts:

- ***Relate potential climate impacts to specific EU policies.*** The impact assessment for the White Paper discussed potential policy responses in a rather general way, because the objective was to put the issue on the agenda, not to already analyse specific threats or responses.
- ***Consider short- to medium term vulnerability.*** Using scenario and other information, we can consider to what extent projected changes in socio-economic conditions over the next few decades would change exposure, sensitivity and adaptive capacity.

The nature of the scenarios and the large uncertainties would prevent a quantitative assessment for these two issues, but a relative, qualitative assessment can be pursued. In the next phase of the project, it will be assessed to what extent existing scenario-based and other information about potential climate change impacts can be associated with specific EU policies. Similarly, it will also be assessed to what extent information about socio-economic drivers can be used to combine it with information about potential climate impacts in an assessment of potential threats. This is not always straightforward: for example economic growth on the one had can increase adaptive capacity, but on the other hand can also increase investments in vulnerable areas and hence increase exposure, making it difficult to assess the net effect.

From a policy perspective, it can be relevant to specifically consider potential implications of low-probability high-impacts scenarios. As reported by the IPCC and others, acceleration of climate change if and when particular thresholds ("tipping points") are crossed cannot be excluded. A key example, as noted above, is the upper bound of the sea level rise assumptions from the AR4 that can be considered to be conservative. When assessing threats to particular policy areas, we will determine the relevance of worst case scenarios on a case-by-case basis.

Conclusions

Existing European scenarios have been developed independently and therefore each of them uses different combinations of emission, climate and socio-economic scenarios, assumptions, projections for different time horizons and communication of uncertainties. This makes it difficult and sometimes impossible to compare the results from different studies and to form a vision of the possible ranges of future developments, needed for a coherent climate adaptation policy. Such a coherent vision requires a standard set of emission, climate and socio-economic scenarios, which can facilitate comparability on European-wide scale. Selection of variables, plausible range for these variables and causal mechanisms and linkages among different processes for such a set will need the deployment of probabilistic methods, with probabilities chosen in consultation with relevant stakeholders. In addition, standardised rules for development of sectoral assessments, based on the above mentioned standardised set of emission, climate and socioeconomic scenarios is also missing, making the results of each comparison of climate impacts in different sectors for the need of adaptation subjective and not transferable.

Most of the existing scenarios suffer from being "too plausible" and almost systematically avoid inclusion of discontinuity (high impact low probability extreme events). This compromises the role of scenarios as a tool for exploring a wide range of possible futures and hence to help to prepare "plan B" in order to be able to act more adequately in extreme situations. The disaster in Fukushima reminded us again that the current risk assessment approach, from which scenarios also are a part, is plagued by severe deficiency.

In conclusion, scenario development has been very much a bottom-up process so far, while European-wide, multi-sectoral assessments for designing a coherent policy require a top-down developed set of scenarios. Bottom-up scenarios have their own role – to explore specific developments in more detail for specific stakeholders. Even these niche scenarios could benefit from taking their boundary conditions from a standardised European-wide scenario set, as it will allow their users to compare their results, to re-use some elements and to help them in searching for good practices from elsewhere.

Table 6.1: Main characteristics of selected scenario exercises for EU policy sectors

Sector	*Scenario project/ authors*	*Time frame*	*Resolution*	*Socio-economic scenarios*	*Focus*
Biodiversity and ecosystems	*A-TEAM*	*2020s,2050s,2080s*	*Europe-wide, grid*	*A1FI, A2, B1, B2*	*Biodiversity loss*
	ALARM	*2050, 2100*	*Europe-wide, EU25*	*A1FI, A2, B1; GRAS, GRAS-CUT, BAMBU, SEDG*	*Biodiversity effects*
	EURURALIS	*2020-2030*	*EU member states, grid*	*NA*	*Land-use change*
Water	*SCENES*	*various*	*Europe-wide, NUTS2, grid*	*Economy First , Fortress Europe, Policy Rules, Sustainability Eventually*	*Water stress*
	PESETA	*2020s, 2080s*	*Europe-wide, grid*	*A2, B2*	*Flooding*
Soils and land use	*PLUREL*	*2025*	*NUTS2*	*A1/High growth, A2/Fragmentation, B1/Cleaner affluence, B2/ Green enclaves*	*Land-use change*
Agriculture	*A-TEAM*	*2020s,2050s,2080s*	*Europe-wide, grid*	*A1FI, A2, B1, B2*	*Yield impacts*
	PESETA	*2020s, 2080s*	*Europe-wide, grid*	*A2, B2*	*Yields, economic impacts*

Sector	*Scenario project/ authors*	*Time frame*	*Resolution*	*Socio-economic scenarios*	*Focus*
	SCENAR	***2020***	***NUTS3/2, HARM2***	***baseline, regionalization, liberalization***	***Sector competitiveness***
Forests	***UNECE/FAO***	***2020***	***Europe-wide (38 countries)***	***baseline and integration scenarios***	***Forest products supply/demand***
	EFI	***2020, 2050***	***EU-27***	***two climate and two forest management scenarios***	***Forest productivity***
Fisheries/Aquaculture	***FAO***	***2015, 2030***	***EU***	***one projection***	***Fisheries demand***
	IFPRI	***2020***	***world***	***one projection***	***Fisheries and aquaculture***
Energy	***20-30 studies***	***All time scales***	***EU***	***various***	***None including climate impacts***
Infrastructure/transport					
Industry and services, including Tourism	***PESETA***	***2020s, 2080s***	***Europe-wide, grid***	***A2, B2***	***Tourisms, economic impacts***
Health	***PESETA***	***2020s, 2080s***	***Europe-wide, grid***	***A2, B2***	***Economic impacts***

Sector	*Scenario project/ authors*	*Time frame*	*Resolution*	*Socio-economic scenarios*	*Focus*
	CEHAPIS	*various*	*generic*	*as available*	*Health impacts*
Coastal areas	*PESETA*	*2020s, 2080s*	*Europe-wide, grid*	*A2, B2*	*Coastal safety*
Urban areas, buildings and telecommunication	*PLUREL*	*2025*	*NUTS2*	*A1/High growth, A2/Fragmentation, B1/Cleaner affluence, B2/ Green enclaves*	*Land-use, urban development*
	ESPON	*2071-2100*	*Europe-wide, NUTS3*	*A1B*	*Territorial development*
	EMCC	*2010*	*Europe-wide*	*4 futures (governance/competition oriented)*	*Construction, telecom*

7 Results from the screening of EU policy areas relevant for adaptation

Introduction

The screening of key policy areas relevant to or associated with the key impacts and main threats (cf. Chapter 4) has been set up by attaching pertinent legally relevant documents and reports to the relevant policy areas. Since some of them (e.g. EIA, SEA, State Aid Control) have implications for various policy areas, we included a 'cross-cutting' section.

A first draft of the table, mainly based on expert knowledge and information available via the EUR-Lex server, has been distributed by DG CLIMA to other DGs for further input on March 9th 2011. Feedback on the policy areas to be considered has been included.

The screening of the content has been performed by several technical experts within the institutions of the consortium in order to identify those policy areas on the EU level which have only taken little or limited action. Screening was performed against the following criteria:

- Policy instruments available, further subdivided into the following questions:
- Is there a reference to climate change and/or adaptation?
- Are there concrete adaptation measures included?
- Are monitoring tools for adaptation foreseen?
- Are EU Guidelines for adaptation available?
- Are mechanisms in place to stimulate adaptation at all levels, including EU policy level and in particular implementation?
- Current EU activities, relevant studies/projects

Based on the results of the screening, each sector has been judged as follows:

Table 7.1: Criteria for judging adaptation efforts

EU adaptation effort	Criteria
No/limited adaptation effort	No reference to climate change adaptation or general statement that adaption is important and no EU activity
Medium adaptation effort	Adaptation is more precisely addressed and some policy action is outlined. Guidelines for adaptation exists,
High adaptation effort	Concrete adaptation measures are included in the policy, Monitoring mechanisms for adaptation might be established.

The final results can be found in an Excel file provided separately.

8 Member States and National Adaptation strategies

For several years, European countries have been undertaking proactive adaptation actions by developing strategies based on future climate change projections. Until now, 12 European countries have adopted National Adaptation Strategies (Germany, UK, France, Belgium, Portugal, Hungary, Sweden, Finland, Norway, Denmark, the Netherlands and Spain) or are in the process of doing so (e.g. Austria, Switzerland, Czech Republic) (see Table 8.2 Current status in EU-27, Norway and Switzerland).

The national adaptation strategies (NAS) mostly mark the first attempt to coordinate the issue of adaptation. They provide a framework for adaptation to be applied on the national level but also include implications for local and regional levels as well as sectoral themes which are not of their competency. In general, national adaptation strategies follow the aim of reducing the vulnerability and/or increasing resilience against climate change effects. Strategies available follow broadly consistent structures and thus include chapters on observed and expected climate change, observed and expected impacts and first generic adaptation recommendations for different sectors and/or regions (Keskitalo 2010). Most of the existing strategies include only a little information on implementation (e.g. monitoring, communication) and therefore, in many countries (e.g. Germany, France) the design of plans for implementation is underway.

The following tables show an overview of NAS adopted or under development for EU-27 plus Norway and Switzerland. For NAS in place Table 8.1 provides information on the respective sectors addressed.

The total number of NAS in place addressing a particular policy area has been used as an indicator for the vulnerability estimate (cf. chapter 10).

Table 8.1: Overview on national adaptation strategies in EU-27 plus Norway and Switzerland (status April 2011 based on EEA Website, Swart et al. 2009 and Keskitalo et al. 2010)

Countries with a national adaptation strategy adopted	Titel	Year	Link	Available in English	Policy Areas addressed in NAS: Soil and Landuse	Agriculture	Forestry	Biodiversity	Fisheries	Water	Energy	Infrastructure/Transport	Industry/ Service (incl. Tourism)	Health	Coastal areas	Urban/ building/ telecom
Belgium	Belgian national cliamte change adaptation strategy	2010	http://www.lne.be/themas/klimaatverandering/adaptatie/nationale-adaptatie-strategie/Belgian%20National%20Adaptation%20Strategy.pdf	yes		☒	☒	☒		☒			☒	☒	☒	☒
Denmark	Danish Strategy for adaptation to a changing climate	2008	http://www.kemin.dk/Documents/Klima-%20og%20Energipolitik/klimatilpasningsstrategi_UK_web.pdf	yes	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒
Finland	National Adaptation Strategy	2005	http://www.mmm.fi/attachments/ymparisto/5kghLfz0d/MMMjulkaisu2005_1a.pdf	yes	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒		☒
France	National Climate Change Adaptation Strategy	2007	http://www.developpement-durable.gouv.fr/IMG/ecologie/pdf/Strategie_Nationale_2.17_Mo-2.pdf	no		☒	☒	☒		☒	☒	☒	☒	☒	☒	☒
Germany	German Strategy for Adaptation to Climate Change	2008	http://www.bmu.de/files/english/pdf/application/pdf/das_gesamt_en_bf.pdf	yes	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒
Hungary	National Climate Change Strategy 2008-2025	2008	http://klima.kvvm.hu/documents/14/nes_080219.pdf	no	☒	☒	☒	☒		☒	☒			☒		
Netherlands	Make Space for Climate	2007	https://www.maakruimtevoorklimaat.nl/english-summary.html	yes	☒	☒	☒	☒		☒			☒		☒	☒
Norway	Climate change adaptation strategy for Norway	2008	http://www.regjeringen.no/upload/MD/Vedlegg/Klima/Klimatilpasning/Klimatilpasning_redegjorelse150508.pdf	no	☒	☒	☒	☒	☒		☒			☒		
Portugal	National Climate Change Adaptation Strategy	2010	http://dre.pt/pdf1sdip/2010/04/06400/0109001106.pdf	no	☒	☒	☒	☒	☒	☒	☒		☒	☒	☒	☒
Spain	National Plan for Adaptation (PNACC)	2006	http://www.mma.es/portal/secciones/cambio_climatico/areas_tematicas/impactos_cc/pnacc.htm	no		☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒
Sweden	Bill: An Integrated Climate and Energy Policy (focus on mitigation)	2009	http://files.eesi.org/sweden_policy_030009.pdf	yes	☒					☒				☒		☒
United Kingdom	Climate Change Act	2008	http://www.opsi.gov.uk/acts/acts2008/pdf/ukpga_20080027_en.pdf	yes	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒

Table 8.2: Countries in the process of developing national adaptation strategies

Countries in the process of developing national adaptation strategies		Scheduled for (year)	Link
Austria	Austria has started the process of developing a national adaptation strategy for various sectors in 2007.	early 2012	http://www.klimawandelanpassung.at/en/
Czech Rebublic	The Czech Rebublic is in the process of developing a national adaptation strategy. The recently published report titled "National Program to abate the climate change impacts in the Czech Republic" addresses mitigation and adaptation issues.	no information (n.i.)	http://www.mzp.cz/C125750E003B698B/en/national_programme/$FILE/OZK-National_programme-20040303.pdf
Estonia	Some sources mention (e.g. Keskitalo et al. 2010, Swart et al. 2009) that Estonia will have an adaptation strategy in place by 2009, but this could not be verified. The project BALTADAPT seeks to develop such a BSR-wide climate change adaptation strategy.	2009?	The strategy could not be found in the internet
Greece	Some sectoral initiatives are in place (e.g. for agriculture, coastal management) but a comprehensive adaptation strategy for the national level has been absent so far (Keskitalo et al. 2010)	n.i.	
Italy	At the national level, progress on adaptation has been delayed through recent governmental instability, but has also maintained some continuity in its approach through its use of existing legislation, policy and knowledge of vulnerable areas as the basis for a national adaptation strategy. (Keskitalo et al. 2010)	n.i.	
Ireland	The Climate Bill has been developed but not officially adopted until now due to the financial crises. The document "National Climate Change Strategy 2007-2012" is available.	2011?	http://www.environ.ie/en/Publications/Environment/Atmosphere/FileDownLoad,1861,en.pdf
Latvia	Latvia does not yet have a national adaptation strategy. An informative report on adaptation was submitted to the government in 2008 (Ministry of the Environment, 2008a), and will serve as a basis for the further development of a national strategy. (Swart et al. 2009) In addition, the project BALTADAPT seeks to develop such a BSR-wide climate change adaptation strategy.	n.i.	
Lithuania	The project BALTADAPT seeks to develop a BSR-wide climate change adaptation strategy. The strategy on sustainability includes some relevant aspects for adaptation to climate change.	n.i.	
Poland	Poland is in the process of developing a national adaptation strategy.	end 2011	
Romania	Some sources indicate, that Romania has developed a strategy to limit emissions of greenhouse gases and deal with the impact of climate change in 2008 but the strategy could not be found in the internet.	2008?	http://www.cowi.com/menu/project/EconomicsManagementandPlanning/Communicationandpolicyadvice/Pages/ClimatechangestrategyforRomania.aspx
Slovak Republic	So far, the focus was on climate change impact assessments. The development of a national adaptation strategy is not planned yet.	n.i.	
Slovenia	A new coordination group for climate change adaptation was established with the aim to prepare a national adaptation strategy. Further steps are still under discussion, especially due to restriction in resources.	n.i.	
Switzerland	Switzerland is in the process of developing a national adaptation strategie for various sectors.	end 2011	-

No information was found for Bulgaria, Cyprus, Luxembourg and Malta

9 Relevant research projects

9.1 EU-funded research projects

Over the past years, more and more projects put their research focus explicitly on the issue of climate change. Research in this field addresses different European regions, sectors and aspects of climate change impacts and adaptation. We have identified 237 EU-funded projects - both ongoing and finalised - with the main focus on climate impacts, vulnerability and adaptation.

We have identified the projects from the following funding programmes and/or web sources:

- INTERREG III B 2000-2006
- INTERREG IV B 2007-2013
- Cordis (projects funded by Framework Programmes FP4 - FP7)
- European Communities 2009 (European Research Framework Programme: Research on Climate Change Prepared for the Third World Climate Conference and the UNFCCC Conference of the Parties);
- European Commission: Research and Innovation - Environment (Link: http://ec.europa.eu/research/environment/index_en.cfm?pg=climate and http://ec.europa.eu/research/environment/index_en.cfm?pg=marine)
- Cost Action
- ERA-net CIRCLE and CIRCLE-2

The projects identified are presented in the table below (9.I) and described in more detail. In case of projects followed by question mark the attribution to a certain theme was not possible due to a lack of information provided in the internet.

Table 9.1: EU funded research projects

Themes	Climate scenarios	Climate impacts	Adaptation to climate change	Damage costs	Adaptation costs	Social issues	Adaptation Measures	Decision support/ Guidance
Soils and land use	- SUDPLAN - ESPON climate	- CLISP - SEAREG - SUDPLAN - ESPON climate	- ESPACE (I and II) - CLISP - C-Change - SUDPLAN	- SEAREG - ESPON climate	- C-Change	- C-Change - SEAREG - SUDPLAN - ESPON climate	- ESPACE (I and II) - ESPON climate	- SEAREG - SUDPLAN
Agriculture	- ADAGIO	- ADAGIO - ACCRETe - *AGRISAFE* - CLIVAGRI - GLOBALCHANGEBIOLOGY - VEG-i-TRADE - CARAVAN	- ADAGIO - Aquarius - ClimaFruit - *AGRISAFE* - VEG-i-TRADE - CARAVAN	- *AGRISAFE*	- Aquarius		- ADAGIO - Aquarius - ClimaFruit - *AGRISAFE*	- CLIVAGRI - GLOBALCHANGEBIOLOGY - CARAVAN
Forestry		- BACCARA - MANFRED - ForeStClim - ILAND - ISEFOR - PYRTREELINEMOD - TRANZFOR - TRECC - FUTUREforest - MOTIVE	- ALP FFIRS - MANFRED - REINFFORCE - ECHOE - ILAND - NOVELTREE - TRANZFOR - FUTUREforest - MOTIVE	- BACCARA - ForeStClim	- NOVELTREE		- ALP FFIRS - REINFFORCE - NOVELTREE - TRANZFOR	- MANFRED - ForeStClim - ECHOES - ILAND - ISEFOR - FUTUREforest - MOTIVE

Themes	Climate scenarios	Climate impacts	Adaptation to climate change	Damage costs	Adaptation costs	Social issues	Adaptation Measures	Decision support/ Guidance
Biodiversity	- HABIT-CHANGE - ECOSPACE - EMMA	- ATEAM - MACIS - HABIT-CHANGE - AIM-HI - INCREASE - ALIENFISH&CLIMCHANGE - ALPINEFRAGMENTATION - AVIAN FLIGHT - BALTIC SEALS HISTORY - BIOTIME - CHAOS - CLIMBIOHOTSPOTS - CORALCHANGE - ECOSPACE - EMMA - GEDA - LRSB - MAREA - RECLAIM - THE WEAKEST LINKS	- BRANCH - MACIS - HABIT-CHANGE - Biochar - BIOTIME - CORALCHANGE - ECOSPACE - EMMA - GEDA - MAREA - THE WEAKEST LINKS	- RECLAIM	- ECOSPACE	- ECOSPACE	- BRANCH - MACIS - HABIT-CHANGE - ECOSPACE - GEDA	- ATEAM - BRANCH - HABIT-CHANGE - Biochar - ALPINEFRAGMENTATION - BIOTIME - CHAOS - EMMA
Fisheries and Aquaculture		- MERSEA - ATP	- MERSEA - MESMA - BALANCE	- ATP			- MERSEA	- MESMA - BALANCE

Themes	Climate scenarios	Climate impacts	Adaptation to climate change	Damage costs	Adaptation costs	Social issues	Adaptation Measures	Decision support/ Guidance
Water management: water safety, scarcity and droughts	- CLIME? - AMICE - DINAS-COAST - BaltSeaPlan	- CLIWAT - DMCSEE - DiPol - CLIME - NeWater - SCENES - WATCH - CLIMATEWATER - WATERWORLDS - IMVUL - ACQWA - Euro-limpacs - SILMAS - CC-WaterS - NO REGRET - ATP - CLAMER - CLIMB - EPOCA - HERMIONE - GENESIS - BASIN - PARAWARM - REFRESH - URBANFLOOD - VIROCLIME - WASSERMed - THOR? - CARBOCHANGE - MedSeA - DINAS-COAST	- PREPARED - ALFA - CLIWAT - FloodResilienCity - MARE - WATER CoRe - AlpWaterScarce - CLIME - NeWater - SCENES - CLIMATEWATER - WATERWORLDS - ACQWA - Euro-limpacs - LABEL - EULAKES - INARMA - SAWA - AMICE - WAVE - CC-WaterS - FLOWS - FRaME - NO REGRET - CORFU - HERMIONE - REFRESH - URBANFLOOD - SIGMA for Water - SHARP - MESMA	- PREPARED - ALFA? - WATER CoRe - CLIME? - SCENES - ACQWA - INARMA - SAWA - AMICE - CC-WaterS - FLOWS - FRaME - ATP - CLAMER - CORFU - WASSERMed - MedSeA - DINAS-COAST - ORFOIS	- PREPARED - ALFA - WATER CoRe - CLIME - SCENES - ACQWA - INARMA - SAWA - AMICE - CC-WaterS - FLOWS - FRaME - CORFU - REFRESH	- PREPARED - ALFA - WATER CoRe - CLIME - NeWater - SCENES - WATCH? - WATERWORLDS - ACQWA - INARMA - AMICE - CC-WaterS - FLOWS - FRaME - CLAMER - CORFU - MedSeA - DINAS-COAST - ORFOIS	- PREPARED - ALFA - MARE - WATER CoRe - AlpWaterScarce - CLIME - NeWater - CLIMATEWATER - WATERWORLDS - ACQWA - Euro-limpacs - LABEL - INARMA - SAWA - AMICE - WAVE - CC-WaterS - FLOWS - FRaME - NO REGRET - CORFU - REFRESH - DINAS-COAST	- CLIWAT - DMCSEE - DiPol - FloodResilienCity - AlpWaterScarce - CLIME - SCENES - WATCH - Euro-limpacs - EULAKES - SILMAS - FLOWS - CLIMB - HERMIONE - GENESIS - URBANFLOOD - SIGMA for Water - SHARP - MESMA - EMWIS - HERMES - BaltSeaPlan - WATERPRAXIS - SPICOSA

		- HERMES - ORFOIS - SESAME IP	- DINAS-COAST - EMWIS - BaltSeaPlan - WATERPRAXIS - SPICOSA					

Themes	Climate scenarios	Climate impacts	Adaptation to climate change	Damage costs	Adaptation costs	Social issues	Adaptation Measures	Decision support/ Guidance
Energy			- BTN - AEOLUS		- AEOLUS		- BTN - AEOLUS	
Infrastructure and transport	- ECCONET - EWENT	- ECCONET - EWENT - EXTREME SEAS	- QUANTIFY - MoCuBa - ECCONET - EWENT - WF - EXTREME SEAS	- ECCONET - EWENT	- ECCONET - EWENT		- QUANTIFY - MoCuBa - ECCONET - EWENT - EXTREME SEAS	- WF
Industry and Services, including Tourism		- ClimAlpTour - CCII	- ClimAlpTour - CCII	- CCII		- CCII	- ClimAlpTour	- CCII
Health		- CCASHh - EDEN - ARCRISK - CLEAR - ICEPURE	- CCASHh - ARCRISK	- CCASHh	- CCASHh	- CCASHh - CLEAR	- CCASHh - ARCRISK	- EDEN

Themes	Climate scenarios	Climate impacts	Adaptation to climate change	Damage costs	Adaptation costs	Social issues	Adaptation Measures	Decision support/ Guidance
Coastal areas		- ASTRA - ATLANTOX - IMCORE - CoastAdapt - Ice2sea - THESEUS - Coastal Sustainability as a Challenge	- COASTANCE - ASTRA - Safecoast -BLAST - IMCORE - CoastAdapt - ESCAPE - THESEUS	- CoastAdapt - THESEUS		- CoastAdapt - THESEUS	- COASTANCE - ASTRA - Safecoast - BLAST - IMCORE - ESCAPE - THESEUS	- ATLANTOX - IMCORE - Ice2sea - THESEUS
Urban areas, buildings and telecom	- SUDPLAN	- GRaBS - NOAH'S ARK - SUDPLAN - URBANFLOOD	- GRaBS - NOAH'S ARK - PREPARED - FloodResilienCity - Future Cities - CAT-Med - MoCuBa - CORFU - SUDPLAN - URBANFLOOD	- GRaBS - NOAH'S ARK - PREPARED - Future Cities - CAT-Med - CORFU	- NOAH'S ARK - PREPARED - Future Cities - CAT-Med - CORFU	- PREPARED - CAT-Med - CORFU - SUDPLAN	- NOAH'S ARK - PREPARED - Future Cities - CAT-Med - MoCuBa - CORFU	- GRaBS - NOAH'S ARK - FloodResilienCity - SUDPLAN - URBANFLOOD

Themes	Climate scenarios	Climate impacts	Adaptation to climate change	Damage costs	Adaptation costs	Social issues	Adaptation Measures	Decision support/ Guidance
Cross cutting	- ADAM - BaltCICA - ClimChAlp - DAMOCLES - ENSEMBLES - MICRODIS - PESETA - CLIMATECOST - CECILIA - Clim-ATIC - Clavier - PRUDENCE - CLARIS LPB - WCC 3	- CLIMSAVE - BaltCICA - BalticClimate - CPA - CIRCE - CIRCLE(2) - ClimChAlp - DAMOCLES - ACCELERATES - ENSEMBLES - MERSEA - MICRODIS - PESETA - MEECE - CLIMATECOST - CCTAME - ENSURE - CECILIA - PermaNET - Clim-ATIC - Clavier - GLOCHAMORE - PRUDENCE - ENHANCE - ASIAN MONSOON - CCECON - CLARIS LPB - WCC 3	- ADAM - AMICA - CLIMSAVE - BaltCICA - CPA - Future Cities - REGIOCLIMA - CIRCE - CIRCLE(2) - ClimChAlp - MERSEA - MICRODIS - CLIMATECOST - CCTAME - Mountain Trip - THARMIT - PermaNET - CAT-Med - Clim-ATIC - GLOCHAMORE - ENHANCE - SIC adapt! - CLARIS LPB - LOWTEV - RESPONSES - RSC	- ADAM - BaltCICA - Future Cities - CIRCE - ClimChAlp - MICRODIS - PESETA - CLIMATECOST - CCTAME - CAT-Med - Clavier - CCECON - WCC 3	- ADAM - BaltCICA - Future Cities - CIRCE - ClimChAlp - CLIMATECOST - CCTAME - THARMIT - CAT-Med - CCECON	- ADAM - CIRCE - ClimChAlp - MICRODIS - PESETA - CLIMATECOST - THARMIT - CAT-Med - WCC 3	- ADAM - AMICA - CLIMSAVE - BaltCICA - CPA - Future Cities - CIRCE - ClimChAlp - MERSEA - MICRODIS - CCTAME - THARMIT - CAT-Med - Clim-ATIC - SIC adapt! - CLARIS LPB - LOWTEV - RESPONSES	- BalticClimate - REGIOCLIMA - CIRCLE(2) - MEECE - CLIMATECOST - Mountain Trip - PermaNET - GLOCHAMORE - PRUDENCE - ENHANCE - SIC adapt! - WCC 3 - RSC

Please note: The compilation of research projects is the result of internet research carried out between May 2010 and December 2010 for the EEA (ETC/ACC). Research in the field of climate change is highly dynamic and thus this overview on research projects is not exhaustive. Question marks in the table relate to some uncertainty in the judgement.

Towards the end of the project, an additional inventory of poassibly relevant projects was received from Climatecost project leader Paul Watkiss, which is attached as Annex 1. While there is a significant overlap, a comparison shows that a multitude of projects is potentially relevant, but in most cases the lack of published results prevents a good identification of relevant ongoing projects in the context of climate change damage or adaptation, a full assessment would be beyond the scope of this report.

9.2 Key findings

From the 237 EU-funded projects collected, 186 projects do address one or more (cross-sectoral) of the main key themes identified for this task. Most of the research projects are focusing on climate change impacts. In this context the water sector and the biodiversity sector are covered mostly. Little research on climate change impacts exists for sectors such as fishery, energy, industry and health. A similar picture can be drawn for research on adaptation to climate change. Not all of the research project which addresses the issue of adaptation will provide concrete adaptation measures as an output of the work.

When looking at the vulnerability criteria used in this study it becomes clear that questions on costs (adaptation and damage costs) are not well researched. Only a few projects are addressing the issue at all. The situation is similar for social issues. Little research has been carried out so far and some sectors such as agriculture, forestry, fisheries do not cover social issues at all.

From an overall view, applying a "low-medium-high" classification accounting for the amount of projects carried out and the vulnerability indicators covered the following overall conclusions can be drawn:

- High research activities can be found for the sectors: Water and Biodiversity
- Medium research activities can be found for the sectors: Agriculture, Forestry, Coastal areas, Urban areas...)
- Low research activities can be found for the sectors: Soil, Fisheries, Energy, Infrastructure, Industry, Health

10 Vulnerability estimate per sector and recommendations for further EU actions

The following table summarises the findings following the overall methodology outlined in chapter 2 and more detailed for each component in chapters 4 to 9.

Table 10.1: Vulnerability estimate per sector

Sectors	Impacts 2025	Estimated Damage Costs 2025	Impacts 2080	Estimated Damage Costs 2080	Estimated Adaptation costs	EU Research activities	Current EU policy efforts	NAS adressing sectoral adaptation	Proposal for priority policy areas to be further screened
Soils and land use	Medium to high negative sectoral effects	Very uncertain but expected to be Low	High negative sectoral effect	Uncertain, but expected to be medium	Soils: Low Land use: High (indirect)	Low	Medium adaptation effort	9 (DK, FI, DE, HU, NL, NO, PT, SE, UK)	no
Agriculture	Limited medium positive (north) to mostly medium negative sectoral effects	Negative (North) to small(South)	Limited large positive effects (north) to mostly large negative sectoral effects	Negative (North) to medium (South)	Medium	medium	Medium adaptation effort	11 (BE, DE, DK, ES, FI, FR, HU, NL, NO, PT, UK)	yes
Forestry	Medium positive to Medium negative sectoral effects	Uncertain but expected to be Low to Negative	Medium positive sectoral effect to large negative sectoral effects	Uncertain but expected to be Negative (North) to High (South)	Medium	Medium	No adaptation effort (just sequestration/ mitigation), not a core issue of EU policy	10 (BE, DE, DK, ES, FI, HU, NL, NO, PT, UK)	no
Biodiversity and Nature Conservation	Medium negative sectoral effects	Uncertain (e.g., valuation issues)	High negative sectoral effects	Uncertain (e.g., valuation issues)	Medium to high	Medium	Medium adaptation effort	11 (BE, DE, DK, ES, FI, FR, HU, NL, NO, PT, UK)	no

Sectors	Impacts 2025	Estimated Damage Costs 2025	Impacts 2080	Estimated Damage Costs 2080	Estimated Adaptation costs	EU Research activities	Current EU policy efforts	NAS adressing sectoral adaptation	Proposal for priority policy areas to be further screened
Fisheries and Aquaculture	Large positive to medium negative sectoral effect	Uncertain	Medium negative sectoral effect to High negative sectoral effects	Uncertain	Unknown	Low	no/limited adapatation effort	7 (DE, DK, ES, FI, NO, PT, UK)	no
Water management	Medium negative effects	High	High negative sectoral effects	High	High	High	High adaptation effort	11 (BE, DE, DK, ES, FI, FR, HU, NL, PT, UK, SE)	no
Energy	Energy demand decreases Supply: Low Infrastructur e: Medium	Energy demand: Negative Supply and infrastructur e: Medium	High negative sectoral effects	Demand: Negative; Supply: Low to Medium infrastructure: High	Medium to high	Low	no/limited adaptation effort (just mitigation)	11 (BE, DE, DK, ES, FI, FR, HU, NL, NO, PT, UK)	yes
Infrastructure and transport	Medium negative sectoral effect and some medium postive effects in the north	High	Medium negative to high negative sectoral effects	High	High	Low	Medium adaptation effort	6 (DE, DK, ES, FI, FR, UK)	yes

Sectors	**Impacts 2025**	**Estimated Damage Costs 2025**	**Impacts 2080**	**Estimated Damage Costs 2080**	**Estimated Adaptation costs**	**EU Research activities**	**Current EU policy efforts**	**NAS adressing sectoral adaptation**	**Proposal for priority policy areas to be further screened**
Industry and Services, including Tourism	Medium negative effects for industry and services and some diverse effects for tourism	Low (Tourism: diverse: High in Southern Europe and Alpine areas and Negative in North)	High negative effects for industry and services and diverse effects for tourism	Low (Tourism: High in Alpine areas and Negative in North)	Low (Tourism: High)	Low	No/limited adaptation effort (tourism is not a core issue of EU policy, industry and sectors are mainly driven by market)	9 (BE, DE, DK, ES, FI, FR, NL, PT, UK)	no
Health	Medium negative to high sectoral effects	Low to High	High negative sectoral effects	Negative to High	Low	Low	Medium adaptation effort	11 (BE, DE, DK, ES, FI, FR, HU, NO, PT, UK, SE)	no
Coastal areas	medium negative sectoral effects	Medium to high	High negative sectoral effects	High	High	Medium	High adaptation effort	8 (BE, DE, DK, ES, FR, NL, PT, UK)	no
Urban areas, buildings and telecom	medium negative sectoral effects	Uncertain, expectedto be Medium to High	High negative sectoral effects	High	High	Medium	No/limited adaptation effort	10 (BE, DE, DK, ES, FI, FR, NL, PT, UK, SE)	yes

Based on the table above the following sectors have been selected in a coordination meeting with the European Commission to be further investigated in task 2 and 3 of this study. The arguments for inclusion are stated as follows:

- Energy: low research and adaptation activities but medium to high estimated adaptation costs
- Agriculture: enough reliable data and information but support the current on-going process of policy formulation is needed as agriculture is one of the main drivers for land use, soil quality and water use.
- Infrastructure and transport: low research and adaptation activities but high estimated adaptation costs
- Urban areas, buildings and telecom: no/limited adaptation effort although high damage and adaptation costs to be expected.

The reason why other sectors have not been further included are:

- Soils and land use: not enough data available to make qualified statements.
- Forestry: Even if there is no/little adaptation effort, forestry is not a main EU policy area and there are only few options (e.g. via CAP) to take action on the European Commission level.
- Biodiversity and Nature Conservation: Biodiversity and Nature Conservation: loss of biodiversity can be stopped best by measures taken in the context of current EU policy instruments (e.g., Natura2000, Birds and Habitats Directives) and measures in other sectors which endanger biodiversity; the issues are already reasonably well studied.
- Fisheries and Aquaculture: not enough data available, high uncertainty on the impacts of climate change, overfishing is expected to be the most relevant driver;
- Water management: already very well studied and several activities underway due to the WFD
- Industry and Services, including Tourism: except tourism low damage and adaptation costs estimated, further it is expected that the market mechanisms will trigger adaptation efforts.
- Health: well studied, EU research activities should be medium to high since there exists an EU centre of the WHO.
- Coastal areas: already very well covered and several activities under the EU Integrated Coastal Zone Management (ICZM) activities

Based on this judgement the next step is to identify the most appropriate measures on the EU level to address those major threats that have been identified and prioritized in this report and will be further investigated for the sectors selected in task 2.1.

11References

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Annex 1: Ongoing projects that may address costs of damage and adaptation (courtesy Paul Watkiss)

Project	Funding	Objectives	Participants	Policy relevance	Links
AMICA (Adaptation and Mitigation – an Integrated Climate Policy Approach)	INTERREG IIIC - project-part financed by the EU	To combine measures to promote climate change adaptation with preventive strategies to maintain and protect the global climate	Germany, Austria Italy, France the Netherlands	Local and regional strategies to climate change (mix of short- and long-term preventive and reactive measures, to planning risks)	www.amica-climate.net
ASTRA (Developing Policies & Adaptation Strategies to Climate Change in the Baltic Sea Region)	INTERREG IIIB - project-part financed by the EU	To assess regional impacts of climate change and develop strategies and policies for adaptation.	Finland, Germany Latvia, Estonia, Lithuania, Poland	Focus on Baltic Sea Region (BSR) and on stressors such as extreme temperatures, droughts, forest fires, storm surges, winter storms, floods.	www.astra-project.org
COMCOAST (Combined functions in Coastal defence zones)	INTERREG IIIB - project-part financed by the EU	To explore coastal defence strategies in the North Sea, plus new methods to evaluate flood defence zones; to develop new flood defence solutions.	The Netherlands, Germany, UK, Belgium, Denmark	Best practice multifunctional flood management solution	http://www.comcoast.org/
INTARESE (Integrated Assessment of Health Risks of environmental stressors in Europe)	EC (6th FP)	Developing and applying new, integrated approaches to the assessment of environmental health risks and consequences.	33 research institutes across Europe	Support of EU policy on environmental health for the assessment of the impacts, vulnerability, and the options to adapt to climate.	http://www.intarese.org/
SEAREG (Sea Level Change Affecting The Spatial Development In Baltic Sea Region)	INTERREG IIIB - project-part financed by the EU	Assess impacts of future sea level rise in several case study areas in the BSR.	Finland, Sweden, Germany	Information on impacts, plus the Decision Support approach is being developed to look at adaptation strategies.	http://www.gtk.fi/projects/seareg/doc.html
EC (7th FP)					
CLIMATECOST (Full cost of climate change)	EC (7 th FP)	To advance knowledge in the full economic costs of climate change	France, UK, Czech Republic, Greece, Denmark, Belgium, Germany, Ireland, Austria, Italy, Spain, India, China	Employing economics of climate change to inform the policy on the long-term targets, the costs of inaction (the economic effects of climate change), and the costs and benefits of adaptation.	http://www.climatecost.cc/ClimateCost/Welcome.html
CLIMSAVE (Climate change integrated assessment methodology for cross-sectoral adaptation and vulnerability in Europe)	EC (7 th FP)	To develop and apply an integrated methodology for climate change impact and vulnerability assessment that explicitly evaluates regional and continental scale adaptation options, and cross-sectoral interactions between the key sectors driving landscape change in Europe.	UK, Romania, Belgium, Hungary, Spain, Germany, Czech Republic, Greece, Austria, Sweden, Netherlands, China, and	Analysis on the policy and governance context for adaptation and investigation on policy options in response to reducing the uncertainty with climate change impact.	http://www.climsave.eu/climsave/

			Australia		
CCTAME (Climate change - terrestrial adaption and mitigation in Europe)	EC (7 th FP)	To assess the efficiency of current and future land use adaptation and mitigation processes and to identify and quantify the adaptation induced by policies	UK, Austria, Spain, Slovakia, Germany, France, Italy, Finland, Denmark, Estonia, Japan	This project is to align and link the currently leading and most suitable land-use models with other climate policy tools to quantify benefits from policy coordination and finally provide consistent policy analysis across sectors including the entire land-use sector.	http://www.cctame.eu/
CONHAZ (Costs of Natural Hazards)	EC (7 th FP)	To provide insights into the methods and terminology used in European case studies in assessing the costs of natural hazards, taking a comprehensive perspective on the costs of natural hazards that includes droughts, floods, storms, and alpine hazards. Then to evaluate these methods and to synthesize the results and give recommendations according to current best practice	France, Germany, Austria, Spain, Italy, and Netherlands	In general, this project aims to provide information to policy development in the fields of natural hazard management and adaptation planning to climate change. The costs and benefits of risk-prevention and emergency response policies will be looked at.	http://cordis.europa.eu/fetch?CALLER=FP7_PROJ_EN&ACTION=D&RCN=93525
EWENT (Extreme weather impacts on European networks of transport)	EC (7 th FP)	To estimate and monetise the disruptive effects of extreme weather events on the operation and performance of the EU transportation system. The methodological approach is based on generic risk management framework that follows a standardised process starting from the identification of hazardous extreme weather phenomena, followed by impact assessment and evaluation on measures and options for negative impact reduction, control and monitoring in short and long-term.	Switzerland, Germany, Finland, Austria, Norway, Cyprus,	The information on the efficiency, applicability and finance needs for adaptation and mitigation measures which will minimise the costs of extreme weather impacts will be useful for the development of management strategies and policy options.	http://cordis.europa.eu/search/index.cfm?fuseaction=proj.document&PJ_LANG=PL&PJ_RCN=11092470&pid=0&q=40203C5BD5FC9C0D456A40BE1F8CEA3A&type=sim
INTERREG IVC 2007-2013					
FUTUREforest	INTERREG IVC 2007-2013	This project looks at: 1) Adaptation of forests to maintain their resilience; 2) How forests can help society adapt to the impacts of climate change; 3) How trees and timber can do more than just lock away carbon. It aims to identify the threats, weaknesses and strengths of Europe's forest as they face up to climate change; developing best management	France, Germany, Bulgaria, Catalonia, Latvia, Slovakia, Wales	To develop together the transferable good practice guides, policy recommendations, strategic guidelines, forest programmes and policy tools.	http://www.futureforest.eu/index.php

		techniques to guide policy makers and stakeholders.			
GRaBS (Green and Blue Space Adaptation for Urban Areas and Eco Towns)	INTERREG IVC 2007-2013	This project has five key objectives: 1) To increase partner expertise on the use of green and blue infrastructure to help new and existing urban development adapt to projected climate change; 2) To identify and influence regional planning policy and delivery mechanisms for adaptation; 3) To develop regional and local adaptation action plans, including a high-level policy statement; 4) To develop and use a risk and vulnerabilities assessment tool, to aid strategic planning for climate change adaptation responses; and 5) To improve community awareness and engagement in the planning process for green and blue infrastructure.	Austria, Greece, Italy, Lithuania, Netherlands, Slovakia, Sweden, and UK	The project will facilitate the exchange of knowledge and experience and the actual transfer of good practice on climate change adaptation strategies to local and regional authorities.	http://www.grabs-eu.org/
RegioClima (Regional cooperation towards adaptation to climate change)	INTERREG IVC 2007-2013	To enhance cooperation among selected EU regions towards avoiding risk and reaping the benefits from a changing climate	Cyprus, Italy, Spain, Estonia, Bulgaria, France, Greece, and Slovakia	Special attentions are given two policy-related actions: 1) integration of adaptation into existing and forthcoming legislation & policies; 2) elaboration of climate change adaptation strategies.	
PRoMPt (Proactive Human Response to Wildfires Breakout: Measure and Prepare for it)[18]	INTERREG IVC 2007-2013	This project, based on previously related activities focused on risk management, intends to move further and deal with exchange of experiences and good practices on methods, action plans or even tools, addressing the forest fires danger and crisis management right after the outbreak of a fire, and in particular, a wild one.	Contact partner: Greece	N A	NA
F:ACTS! (Forms for: Adapting to Climate Change through Territorial Strategies!)	INTERREG IVC 2007-2013	This project aims to fill the gap between the increasing body of scientific research and the concrete and necessary preparation at regional and local level.	Contact partner: Netherlands	NA	NA

[18] The information on this project is available only on the list of INTERREG IVC Projects approved. No further information can be found beyond this.

FLOOD-WISE (Sustainable flood management strategies for cross border river basins)	INTERREG IVC 2007-2013	The FLOOD-WISE project stimulates a joint approach in sustainable flood management in 6 international river basins (Meuse, Roer, Elbe, Sava, Western Bug and Tisza-Somes). Overall objective of the project is identification, sharing and transfer of good practices on sustainable cross-border flood management in European river basins, using the instruments of the Flood Risk Management Directive (FRMD).	Contact partner: Netherlands	NA	NA
INTERREG IVB North Sea Region 2007-2013					
Aquarius (The farmer as water manager under changing climatic conditions)	INTERREG IVB North Sea Region 2007-2013	By conducting pilot projects, this project aims to find and implement sustainable, integrated land-water management through engaging with land managers, in response to the opportunities and challenges brought by climate change.	Denmark, Germany, Netherlands, Norway, and UK	The final result of the project is a water management concept to use as a manual for farmers and a set of recommendations on future land and water management planning.	http://www.aquarius-nsr.eu/Aquarius.htm
ClimaFruit (ClimaFruit Future proofing the North Sea berry fruit industry in times of climate change)	INTERREG IVB North Sea Region 2007-2013	By connecting the horticultural sector with EU, regional & national governments, this project aims to strengthen the future sustainability of the north sea region berry fruit industry against risk from climate change & add value to secure the long-term future of NSR fruit industries.	Denmark, Sweden, Norway, UK, and Germany		http://www.northsearegion.eu/ivb/projects/details/&tid=122&back=yes
CLIWAT (Adaptive and Sustainable Water Management and Protection of Society and Nature in an Extreme Climate)	INTERREG IVB North Sea Region 2007-2013	To initiate important transboundary cooperation and evaluation of the effect of different climate scenarios in the EU North Sea region and establish predictive modelling tools for future simulations	Denmark, Germany, Netherlands, and Belgium		http://cliwat.eu/about_us/index.html
CPA (Climate Proof Areas)	INTERREG IVB North Sea Region 2007-2013	The aim of the project is to accelerate the climate change adaptation process in the NSR by means of the joint development and testing of innovative adaptation measures in pilot locations for a variety of areas representative for the NSR as a whole, and use the results to give recommendations for regional, national and NSR wide adaptation strategies and create a toolkit for adaptation in the NSR, thus	Sweden, Netherlands, Belgium, UK, and Germany		http://www.climateproofareas.com/

		preparing these regions, countries and the NSR for anticipated changes in the climate.			
Dipol (Impact of Climate Change on the quality of urban and coastal waters)	INTERREG IVB North Sea Region 2007-2013	The project aims to identify impacts and suggesting measures to reduce the adverse consequences of climate change that affect the quality of urban and coastal waters. A programme tool that illustrates the impacts of climate changes on water quality will be developed and implemented within this project.	Germany, Norway, Netherlands, Sweden, Denmark,	By introducing the results into the level of European policy making, a long term impact on the Water Framework Directive and the Marine Strategy is expected.	http://www.tu-harburg.de/iue/dipol.html
SAWA (Strategic Alliance for integrated Water Management Actions)	INTERREG IVB North Sea Region 2007-2013	To adapt existing water management systems to the effects of extreme flood events due to climate change, focusing on sustainable development of society and regional economies. Based on case studies and pilot implementations, this project sets out to test the new and innovative strategies in Flood Risk Management around the North Sea.	Netherlands, UK, Norway, Sweden, and Germany		http://www.sawa-project.eu/index.php
INTERREG IVB North West Europe					
ALFA (Adaptive Land use for Flood Alleviation)	INTERREG IVB North West Europe	The general aim is to protect the North West Europe region against the effects of (the risk of) flooding due to climate changes. The project focuses on flood adaptation measures and interventions. This will be done by creating new capacity for storage or discharge of peak floods within river catchments in Belgium, France, Germany, United Kingdom and The Netherlands.	Netherlands, Belgium, Germany, France and UK	Knowledge and experiences arising from trans-national cooperation in developing and implementing policy measures in the project areas will be shared between the six river catchments.	http://www.alfa-project.eu/en/about/
AMICE (A coordinated strategy for the Adaptation of the Meuse to the Impacts of Climate Evolutions on floods and low-flows with the perspective of sustainable development in the Meuse international catchment basin.)	INTERREG IVB North West Europe	This project aims to produce a coordinated strategy of adaptation to the impacts of climate change on water quantities, in the international Meuse basin. It will take into account on-going projects, existing measures, the Floods Directive (2007/60/EC) and focus on both floods & droughts. It aims to use the most innovative practices of prevention, protection &	France, Belgium, Germany and Netherlands	Strategies developed in this project	http://www.nweurope.eu/index.php?act=project_detail&id=3868

		preparedness to water-related crisis and propose new measures. The application of these measures is expected to be transferable to other river basins in the North West Europe.			
ForeStClim (Transnational Forestry Management Strategies in Response to Regional Climate Change Impacts)	INTERREG IVB North West Europe	The development of transnational coordinated forestry management and forest protection and adaptation strategies will be the principal outcome of the project	Germany, France, Luxembourg, UK and the Netherlands,	Strategies for transnational forestry management	http://www.forestclim.eu/
Future Cities (Future Cities Urban Networks to Face Climate Change)	INTERREG IVB North West Europe	This project aims at making city regions in Northwest Europe fit to cope with the predicted climate change impacts by proactive transformation of urban structures. The Future Cities-Partnership develops concepts and implementation strategies which: · are innovative — not yet implemented on the practical level · save from greater financial loss — by operating proactively · provide for synergy effects and cost-effectiveness — by applying combined measures.	Germany, the Netherlands, UK, France and Belgium	Strategic measures to transform the urban structures	http://www.future-cities.eu/
FloodResilienCity (Improved integration of increased urban development and flood risks in major cities)	INTERREG IVB North West Europe	This project aims to integrate the increasing demand for more houses and other buildings with the increasing need for more and better flood risk management measures in North West European cities along rivers. The project seeks to adapt the Scottish Sustainable Flood (risk) Management framework as a basis for the joint FloodResilienCity strategy. This strategy will make cities undergoing major urban development more resilient to flood water.	The Netherlands, Belgium, France, Germany, Ireland and UK	The project hopes to reinforce the importance to address 'Awareness, Avoidance, Alleviation, and Assistance' in public policies to achieve Sustainable Flood risk Management.	http://www.nweurope.eu/index.php?act=project_detail&id=3853
WAVE (Water Adaptation is Valuable for Everyone)	INTERREG IVB North West Europe	The main aim is to prepare for future changes in regional water systems brought about by climate change. It will contribute to the development	Belgium, Germany, Ireland, France, Luxembourg, the Netherlands	Policies that prevent damage and address opportunities will be developed.	http://www.waveproject.eu/

		of more climate-proof water systems. It intends to improve the integration of water management into spatial planning and regional risk analysis is an important aspect of this.	and the UK		
INTERREG Baltic Sea Region					
BaltCICA (Climate Change: Impacts, Costs and Adaptation in the Baltic Sea Region)	INTERREG Baltic Sea Region	It is to focus on the most imminent problems that climate change will cause in the Baltic Sea Region - changes in the occurrence of floods (river floods as well as storm surges) and sea level rise, as well as impacts on water availability and quality. A multi-level trans-national approach aims to be applied: concrete adaptation measures are going to be tested and implemented at the case study level; on a pan-Baltic level the costs of higher sea level and increased flood risk will be assessed. A concept for process management on climate change adaptation and mitigation will be developed supported by a meta-evaluation and conceptualization of case study results.	Finland, Estonia, Latvia, Lithuania, Denmark, Sweden, Norway, Germany,	Integrated adaptation measures and the associated assessment on costs and benefits	http://www.baltcica.org/
BALTRAD (An advanced weather radar network for the Baltic Sea Region)[19]	INTERREG Baltic Sea Region	The objective of this project is to create a cutting-edge real-time weather radar network for the Baltic Sea Region.	Denmark, Estonia, Finland, Poland, Latvia, Belarus and Sweden		http://baltrad.eu/
Projects at the national level					
WaterAdapt (Finland's water resources and climate change - effects and adaptation)	Climate Change Adaptation Programme ISTO projects (2006-2010)	Aims to evaluate the impacts of climate change on the occurrence of heavy rains, water resources, floods and droughts, and what measures should be taken to adapt to these changes. The following issues are also examined: the pressures to change regulation practices, minimum building site elevations and water supply	Finland	The results of the study can be used in the evaluation of future needs to change the rules and practices of regulation.	http://www.mmm.fi/en/index/frontpage/ymparisto/ilmastopolitiikka/researchprogrammeonadaptationtoclimatechange/water.html

[19] This project does not set out to address the issue with climate change. However, to establish an advanced weather warning system is an adaptation measures and hence we include this project in the list of studies.

		management measures due to climate changes.			
TOLERATE (Towards levels of required adaptation to cope with extreme weather events)	Climate Change Adaptation Programme ISTO projects (2006-2010)	Aims to develop ways to assess what is a reasonable level of adaptation to avoid unacceptable disruption. In addition to the likelihood of extreme events, the impacts of weather-induced disruptions in different sectors, the related damage, and the current trends in economy, technology and institutional organisation, the cost-effective alternatives to lower the risk of disruptions for various sectors are also investigated.	Finland		http://www.mmm.fi/en/index/frontpage/ymparisto/ilmastopolitiikka/researchprogrammeonadaptationtoclimatechange/tolerate.html
ADAPTFVR (Impacts of Climate Change on the emergence of the Rift Valley fever vectors in Senegal and adaptation strategy for better management of pastoralism in Sahel)	GICC Programme (Management and impacts of climate change)[20]	Details not available yet	France		
SAOPOLO (Adaptation strategies of marine protection works or Coastal tenure concerning the rising sea and ocean levels)	GICC Programme (Management and impacts of climate change)	Details not available yet	France		
Adaptation of the Alpine territories regarding the increasing droughts in a context of global change	GICC Programme (Management and impacts of climate change)	Details not available yet	France		
EXCLIM (Managing the displacement of people due to extreme weather)	GICC Programme (Management and impacts of climate change)	Details not available yet	France		
AnKliG (Adaption Strategies for Climate Change and Extreme Weather Conditions and Measures for a	Klimazwei programme	To assess the effects of climate change on the groundwater balance and to develop adaptive actions and strategies for a sustainable	Germany		http://klima-gw.bgsumwelt.de/

[20] The projects under the GICC programme are successful bidders in the call of CRP 2008. These projects are expected to start by the end of 2009 and have the first result by 2011. The funding period is 3 years.

Sustainable Groundwater Management)		groundwater management.			
GIS-Klischee (Adaptation of Winter Sports Tourism to Climate Change and Weather Variability in German Low Mountain Ranges)	Klimazwei programme	The impacts on winter sport tourism will be assessed on probable change scenarios for an area, derived from regional climate model calculations. Investment decisions can be prepared and different adaptation strategies can be suggested depending on the modelled snow cover availability.	Germany		http://www.gis-klischee.de/
Management of Climate Change Effects in the Metropolitan Region Hannover-Braunschweig-Göttingen	Klimazwei programme	To indentify and discuss possible effects of the climate changes To discuss integrative management tools and planning instruments needed to handle the climate change effects	Germany		http://www.klimafolgenmanagement.de/Englisch.htm
RegioExAKT – Regional Risk of Convective Extreme Weather Events: User-oriented Concepts for Climatic Trend Assessment and Adaptation	Klimazwei programme	To investigate the determination of the trends in occurrence of, and threat by, severe convective storms in (southern) Germany until 2030, as well as the development of adaptation concepts for targeted main users: Munich Reinsurance Group and Munich international airport on the spatial and temporal scales relevant for their business operations. To help to enable timely adaptation of business strategies in the insurance industry and of building codes to the severe weather hazard expected until 2030.	Germany		
SAFE (Sensor-Actuator-Based Early-Warning System for Hazard Protection in Extreme Weather Conditions)	Klimazwei programme	This project is to search, implement, and test new technologies for improved local prediction and better warning dissemination and hence provide a better protection from damages from extreme weather events.	Germany		http://www.safe-projekt.de/index.php?lang=en
Simulation-Supported Automation for Sustainable Air-Conditioning of Buildings in Summer	Klimazwei programme	The processes for automatically adaptive building control which includes weather forecast data will be developed and tested in this project.	Germany		http://www.zafh.net/index.php?id=206&L=1

		Manufacturers of building automation systems and building management tools are integrated in the project and the first application of the technology will take place in commercial buildings.			
Climate Change Adaptation of Wheat Production in Germany through Plant Breeding	Klimazwei programme	It is to find a cost-effective possibility for the adaptation to climate change in the context of plant breeding research. A main focus lies in the pre-drawing of flowering time in winter wheat to deal with early summer drought. It will be investigated, if new varieties with an earlier flowering time achieve an advantage in competition in wheat production, when grown under changed climatic conditions, and if positive effects on a sustainable production system can be expected.	Germany		http://www.klimazwei.de/ProjektezumSchutzvorKlimawirkungen/Projekt%C3%BCbersicht/Weizen/tabid/109/Default.aspx
The impact of climate change on the critical weather conditions at Schiphol airport	Climate Changes Spatial Planning and Knowledge for Climate Research Programmes	Aims to quantify and better understand how climate change affects the weather conditions at the airport, and contribute to determine which adaptation strategies are most effective to make the airport 'climate proof'.	The Netherlands		http://promise.klimaatvoorruimte.nl/pro1/publications/show_publication.asp?documentid=3028&GUID=%7BC3ACD46B%2DE164%2D4ECF%2DB6C7%2DDC9AAB766D5F%7D
Heat Stress in the city of Rotterdam	Climate Changes Spatial Planning and Knowledge	This project aims to predict the urban heat island effect in Rotterdam and identify the most relevant options or strategies for the city, including an recommendation concerning the implementation of the strategies is practice.	The Netherlands		http://promise.klimaatvoorruimte.nl/pro1/publications/show_publication.asp?documentid=3028&GUID=%7BC3ACD46B%2DE164%2D4ECF%2DB6C7%2DDC9AAB766D5F%7D
Valuation in economic terms	Climatool research programme	The aim of the project is to evaluate the effects of climate change and adaptation in economic terms.	Norway		http://www.foi.se/FOI/templates/Page____8606.aspx