RANKED AMONG THE WORLD'S TOP 10 THINK TANKS

CEPS Working Document

Thinking ahead for Europe

CENTRE FOR EUROPEAN POLICY STUDIES

Future Impacts of Climate Change across Europe

CEPS Working Document No. 324/February 2010

Arno Behrens, Anton Georgiev and Maelis Carraro

Abstract

This CEPS Working Document reviews the potential impacts of climate change on 11 key indicator categories and 3 large regions covering the entire European Union. Although there remains a considerable degree of uncertainty about local and regional effects, the paper highlights strong distributional patterns. Northern Europe might even experience some positive effects, while the Mediterranean will mostly be negatively affected. Still, the cumulative impacts of climate change on poorer countries will also affect northern European countries, as growing water scarcity and other repercussions in Mediterranean countries could pose social and security challenges through increasing risks of conflicts and migration pressures.

The impacts outlined in this paper are a useful starting point for policy-makers when shaping effective adaptation policies for Europe. They underline the need for a European response in the spirit of solidarity, while stressing that the fight against climate change is clearly in the self-interest of the EU and *all* of its member states.

ISBN 978-92-9079-972-6
Available for free downloading from the CEPS website (http://www.ceps.eu)

Contents

Introduction and methodology 1

Beyond uncertainty and variability: Main findings of the review 2

1. Direct losses from weather disasters 4
2. River flood disasters 5
3. Coastal flooding 6
4. Public water supply and drinking water 7
5. Crop yields in agriculture 8
6. Crop yields in forestry 9
7. Biodiversity 9
8. Energy for heating and cooling 10
9. Hydropower and cooling for thermal plants 12
10. Tourism and recreation 13
11. Health 14

Conclusions 15

Bibliography 16

Appendix I. Complete list of literature reviewed for the assessment of climate change impacts 22

FUTURE IMPACTS OF CLIMATE CHANGE ACROSS EUROPE

CEPS WORKING DOCUMENT NO. 324/FEBRUARY 2010

ARNO BEHRENS, ANTON GEORGIEV AND MAELIS CARRARO*

Introduction and methodology

The objective of this CEPS Working Document is to summarise different projections of the impacts of climate change on the European Union. Based on a review of various studies, the paper presents the latest evidence on the possible effects of climate change on 11 indicators, thus allowing for conclusions regarding potential, future adaptation measures. While the paper generally focuses on the long-term perspective until well into the second half of this century, key trends beyond (as well as those prior to) 2050 are presented where available. The trends are described primarily in a qualitative manner with quantifications presented where possible.

The results presented in this paper are based on a review of the most important recent studies on the impacts of climate change (for a detailed description of references, see Appendix I). The studies reviewed include reports from the Intergovernmental Panel on Climate Change (IPCC), the European Environment Agency (EEA), the European Commission (including the Commission Staff Working Documents accompanying the White Paper on Adaptation) and the Atomic Energy Authority (AEA). The review has also covered the reports, articles and deliverables of selected research projects, including the following EU-funded ones: ADAM, ALARM, ASTRA, ATEAM, cCASHh, CIRCE, CLAVIER, ENSEMBLES, MACIS, MICE, MONARCH, PESETA, PRUDENCE and STARDEX. The final results of some current projects were not available when this paper was finalised; however, the respective organisations and authors were contacted with requests for preliminary findings. The bulk of the final findings from the CECILIA and CLAVIER projects (except those cited in other research reports), as well as a number of papers from other completed projects, remained inaccessible to our research team within the timeframe available for this study. Careful scrutiny of two projects revealed that most of their results were not of use. DINAS-COAST developed a tool for vulnerability assessment to be used in future research. The results of the COCONUT project have been integrated into those of MONARCH and therefore only the latter is cited.

This working document does not go beyond the impacts and does not explain how these would be affected by possible adaptation measures. By and large, the studies reviewed include autonomous adaptation[1] in the effects projected, but do not account for planned adaptation.[2] The PESETA project takes into account private adaptation in estimating the socio-economic consequences (farm-level adaptation in agriculture, changes in tourism flows in the tourism assessment, acclimatisation in the human health study and migration to safer areas in coastal

* Arno Behrens is a Research Fellow and Head of Energy at CEPS, Anton Georgiev is a Researcher at CEPS and Maelis Carraro was an intern at CEPS.

[1] Autonomous adaptation is adaptation that does not constitute a conscious response to climatic stimuli, but is triggered by ecological changes in natural systems and by market or welfare changes in human systems. It is also referred to as spontaneous adaptation (Aaheim et al., 2008).

[2] Planned adaptation is adaptation that is the result of a deliberate policy decision, based on an awareness that conditions have changed or are about to change and that action is required to return to, maintain or achieve a desired state (Aaheim et al., 2008).

systems). In addition, it considers the extent of the effects with and without public adaptation measures (e.g. dykes) for the coastal systems assessment (Ciscar et al., 2009).

Our assessment of climate change scenarios attempts to break down the impacts of climate change on Europe into 11 indicator categories and 3 large EU regions. The following selection of 11 indicator categories is based on EEA (2008) and the Commission Staff Working Document on adaptation (European Commission, 2009a):

- Direct losses from weather disasters
- River flood disasters
- Coastal flooding
- Public water supply and drinking water
- Crop yields in agriculture
- Crop yields in forestry
- Biodiversity
- Energy for heating and cooling
- Hydropower and cooling for thermal plants
- Tourism and recreation
- Health.

The different effects of climate change on these 11 impact categories are analysed by distinguishing among 3 large EU regions: northern Europe (including Belgium, Denmark, Estonia, Finland, Ireland, Latvia, Lithuania, the Netherlands, Sweden and the UK), Central and Eastern Europe (including Austria, Bulgaria, the Czech Republic, Germany, Hungary, Luxembourg, Poland, Romania, Slovakia, Slovenia and the northern part of France), and the Mediterranean countries (including Cyprus, Greece, Italy, Malta, Portugal, Spain and the southern part of France). This grouping differs from the studies reviewed, but was chosen as the most convenient (if somewhat arbitrary) way to form three regional groups with comparable climate characteristics.

Initially, we attempted to summarise the results of a scenario with a global mean temperature increase of two degrees Celsius (2°C) above pre-industrial levels (or about 1.5°C above 1990 levels) by the end of the 21st century, in line with the EU's global climate-change goal, also acknowledged by the Copenhagen Accord. Yet, because of the diverse predictions of various studies under different climate models, it was impossible to build one coherent scenario. Thus, for the sake of completeness, we integrated the key results of a selection of studies that use several different scenarios.

Beyond uncertainty and variability: Main findings of the review

Climate change will have serious socio-economic consequences for Europe in the long term but some effects, such as an increasing frequency of extreme events and weather disasters, will be felt in the short term (European Commission, 2009a). At the same time, the impacts of climate change will vary across European regions and sometimes from even one member state to another. The three large climatic zones in Europe (as described above) will therefore need different regional responses (European Commission, 2009a). Along with the mixed physical impacts in each region, various sectors will be affected in different ways.

Indeed, the *variability* of the natural climate itself and therefore the variability of the impacts of climate change across Europe makes it hard to give an accurate, top-down assessment of them and to design appropriate policy responses. A bottom-up focus on the different regional implications of climate change across Europe gives a better and more specific understanding in order to address the issue adequately. Many of the recent projects in the literature list in Appendix I take this relatively new bottom-up approach to modelling climate change impacts. Hence, this study takes advantage of state-of-the-art advances in disentangling variability. On the other hand, some bottom-up project results are valid only for a few regions or sectors and as such are hardly comparable.

This literature review focuses on the regional and sectoral variability of climate change effects. It must be kept in mind, however, that such variability is not the only factor that increases the uncertainty of the regional projections of climate impacts. Such projections often differ from study to study depending on the models employed, leading to contrasting results for the same region.

The *uncertainty* of impacts can be rooted in the uncertainty about future, geophysical climate changes. This uncertainty tends to grow with an increase in the detail of regional or even local projections (EEA, 2008). That is because each regional model simulation consists of more components than the global one, each with its inherent uncertainty. Uncertainties are thus the result of future global GHG emissions and the underlying dynamic forces driving them, of the internal climate variability ("natural variability") and of the deficiencies of the global and regional climate models employed.[3] At the level of impacts, unpredictable components of socio-economic development are added to the gaps in knowledge and data (EEA, 2008).

The aim of this literature review is not to reduce uncertainty by improving data and knowledge gaps with the help of more recent data. It should rather be regarded as a reminder of the presence of uncertainty in the studies reviewed in order to inform policy-makers about the risks associated with policy approaches to adaptation.

An important added value of this study over previous assessments of the effects of climate change is that it includes a further regional diversification of the repercussions for each climate change indicator. This allows for a differentiated policy analysis by region and impact. Furthermore, our assessment includes the findings of the ADAM and the PESETA projects, which have not been available to prior analyses.

The findings on the magnitude of the effects are summarised in Table 1 and described in detail for each indicator below.

Table 1. Simplified summary of climate change impacts in Europe and their intensity

Climate change indicators	Northern Europe	Central and Eastern Europe	Mediterranean
Direct losses from weather disasters	M(-)	M(-)	H(-)
River flood disasters	M(-)	H(-)	L(-)
Coastal flooding	H(-)	M(-)	H(-)
Public water supply and drinking water	L(-)	L(-)	H(-)
Crop yields in agriculture	H(+)	M(-)	H(-)
Crop yields in forestry	M(+)	L(-)	H(-)
Biodiversity	M(+)	M(-)	H(-)

[3] See Gobiet and the WegCenter-ReLoClim Team (2009).

Table 1. cont'd

Energy for heating and cooling	M(+)	L(+)	M(-)
Hydropower and cooling for thermal plants	M(+)	M(-)	H(-)
Tourism and recreation	M(+)	L(+)	M(-)
Health	L(-)	M(-)	H(-)

Notes: H: High; M: Medium; L: Low; (+): Positive impact; (-): Negative impact

Source: Author's compilation.

1. Direct losses from weather disasters

Changes in the frequency of extreme weather events, such as storms, hurricanes, floods and heat waves, can have direct and greatly negative socio-economic consequences for the EU and its member states. Weather-related disasters or extremes are projected to increase all over Europe but they will vary among regions in terms of the intensity, frequency and typology of the disaster.

Northern Europe will face more storms, resulting in storm surges and coastal erosion, which will be more pronounced and more frequent in the Baltic and North Sea regions (especially Denmark and the Netherlands) (European Commission, 2009e; IPCC, 2007b). The PRUDENCE and ASTRA projects, which deal with climate adaptation strategies in the Baltic Sea regions, also predict an increase in extreme precipitation events, droughts, heat waves and increased frequency of floods (Hilpert et al., 2007; PRUDENCE, 2005).

Already by the 2020s, the risk of extreme precipitation floods will escalate significantly in northern Europe. Various scenarios show a shift of snowmelt floods from spring to winter and a higher risk of flash floods owing to a rise in short-duration precipitation (IPCC, 2007b). By the 2070s, today's 100-year floods will occur more often, especially in Finland, Ireland and Sweden. Findings from the MICE project show that the number of episodes of heavy and extreme rainfall could increase, either absolutely or as a proportion of the total rainfall. These changes in heavy rainfall events have implications for flash flooding, urban drainage, water management, erosion, slope stability and ground water recharge (MICE, 2005; STARDEX, 2005). On the other hand, the EEA (2008) indicates that spring snow floods will decrease, due to a shorter snow season and less snow accumulation in warmer winters. It also predicts an exacerbation of river flow drought in the UK and the Benelux countries, because dry periods are likely to become more common in summer. Thus, the impact of climatic changes in snow and rain patterns on flood regimes can be both positive and negative, highlighting the uncertainty (Bates et al., 2008).

Droughts are also likely to increase in Central and Eastern Europe – western Germany will especially suffer from more river flow droughts. A study by Leckebusch et al. (2007) indicates a high risk of increasing loss potential for the central European regions because of a surge in temperatures and droughts (Leckebusch, 2007). Regions such as central France and Hungary, for example, may experience as many days per year above 30° in the future as are currently experienced in Spain and Sicily (PRUDENCE, 2005). Significant rises in temperature extremes by the end of the 21st century are likewise expected in the German Rhine region (STARDEX, 2005). The projected escalation in drought and heat stress risks in the period 2030–60 is expected to have a negative effect on crop yields at +2°C of global warming (Mechler et al., 2009). Yet, the countries most prone to a spread of drought risk are in the Mediterranean region (EEA, 2008; IPCC, 2007b; Mechler et al., 2009).

Mediterranean Europe will face more extreme temperature increases, continuous droughts, occasional flash floods and more forest fires. Greece, Portugal and Spain are particular hot spots, which are likely to suffer from water scarcity and loss of agricultural yields owing to desertification (EEA, 2008). In parts of southern/central Spain, it is likely that droughts will occasionally persist throughout the year. The resulting stress on water resources, combined with higher summer temperatures, will probably lead to a shift in the main seasons for the tourism sector as well. Moreover, MICE project results suggest that southern France can also expect several months of summer drought every year, with considerably reduced rainfall in winter (MICE, 2005). But there is recent evidence that some of these projections for droughts and heat waves may be overestimated due to the parameterisation of soil moisture in regional climate models (Lenderink et al., 2007 in Bates et al., 2008). Predictions for the likelihood of forest fires under both the SRES[4] A2[5] and B2[6] scenarios analysed by the team of the ENSEMBLES project for a 2°C global temperature increase (reached between 2026 and 2060) are more accurate. Fire risk is shown to grow nearly everywhere in the Mediterranean region, especially in inland locations. In the Iberian Peninsula, northern Italy and over the Balkans, the period of extreme fire risk lengthens substantially (Giannakopoulos et al., 2005).

2. River flood disasters

Losses from river flood disasters in Europe have worsened in recent years and climate change is expected to exacerbate this trend. The PESETA study, for example, estimates that by the 2080s, some 250-400 million Europeans (depending on the scenario assumptions) could be affected each year (compared with 200 million in the period between 1961 and 1990). At the same time, annual losses due to river flooding in Europe could rise to €8-15 billion by the end of the century compared with an average of €6 billion today (Ciscar et al., 2009). While the Nordic and Baltic member states would have fewer damages, an increase in negative consequences is expected elsewhere, mainly concentrated in Central and Eastern Europe, as well as in the British Isles.

In northern Europe, flash and urban floods will be more frequent, causing great damage to the affected countries' economies. Especially hit will be the Netherlands and the UK. Indeed, the European Commission indicates, in the light of a study from WL Delft Hydraulics (see European Commission, 2009a), that in the Netherlands the potential economic losses from flooding could climb by 22-45% in 2040. In the UK, it is estimated that flood risks will increase 10-20 times by 2080 under high emissions and high economic-growth scenarios (European Commission, 2009a).

Estimates from the upper Danube also show that flood damage will increase, by 19% under the B2 scenario and 40% under the A2 scenario by 2100. Damages will similarly increase in the

---

[4] The 40 scenarios of SRES (Special Report on Emissions Scenarios) fall into various groups: the three scenario families A2, B1 and B2, plus different groups within the A1 scenario family. The A1 groups are distinguished by their technological emphasis – on coal (A1C), oil and gas (A1G), non-fossil energy sources (A1T) or a balance across all sources (A1B) (IPCC, 2000).

[5] The SRES A2 scenario family describes a heterogeneous world with regionally oriented economic development and high population growth. Per-capita economic growth and technological change are slower than in the other scenarios. Global concentrations of CO_2 increase to around 700 ppm in 2080.

[6] The SRES B2 scenario family describes a world in which the emphasis is on local solutions to socio-economic and environmental sustainability. It is a world with moderate population growth, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. Global concentrations of CO_2 increase to around 550 ppm in 2080.

Boreal regions, where flash flood risks will be much higher due to a rise in intense precipitation and frequent severe storms (AEA, 2007).

In Central and Eastern Europe, flash and urban floods are also likely to take place more often, especially because of a large surge in rainfalls, predominantly during winter (Aaheim et al., 2008; AEA, 2007). By contrast, in summer a decrease in rainfalls is expected, leading to the opposite consequence: drought.

The AEA predicts a substantial rise in annual rainfall and precipitation mainly in Austria, the Czech Republic, Eastern Germany, Poland and Slovakia. This will lead to a greater risk of flooding from rivers. Hungary and Romania will also have the same problem during winter, which will negatively affect various parts of the economy, particularly the agricultural sector.

The Mediterranean appears to be less vulnerable to river floods. Nevertheless, some projections still include occasional flash flooding from rivers despite lower rainfalls and risks of continuous droughts.

3. Coastal flooding

Without adaptation measures, losses related to coastal flooding are expected to increase considerably. While in 1995, some 36,000 Europeans were affected by sea floods, this number could reach some 5.5 million people (at a temperature increase of 5.4°C for the EU in the 2080s) (Ciscar et al., 2009). Many European cities are at risk of coastal flooding because they are exposed to a rise in the sea level and it is predicted that some cities will even disappear under the sea level if no action is taken. In the PESETA project, the results of the model assessing the impacts of a rising sea level and flooding from storms in Europe estimate that by 2085, under the SRES A2 scenario (a +3.9°C to +5.4°C rise in the EU) without adaptation, between 2,000 and 17,000km² of land in Europe could be lost (European Commission, 2009e). Still, adaptation measures can substantially reduce the number of people affected as well as those displaced by land loss.

The IPCC and Bates et al. (2008) predict that coastal areas in northern Europe will be severely affected and will experience a significant increase in flood frequency. For the Baltic and Arctic coasts, the projected effects of rising sea levels and the heightened risks of flooding and coastal erosion will be evident after 2050. This is in accordance with the findings of the ASTRA project, which predicts an increase in storm surges, river floods, costal erosion and a great sea-level rise in the Baltic Sea Region (Hilpert et al., 2007).

According to the EEA and the European Commission in its *Regions 2020* report, the UK will greatly suffer from coastal flooding (European Commission, 2009e). Estimates show that a 40cm rise in sea levels will put an extra 130,000 properties at risk of flooding in the UK (EEA, 2008). Furthermore, they assert that under a scenario of a 0.5m rise in the sea level by 2100, the assets exposed to extreme flooding in the cities of Amsterdam, Copenhagen, Glasgow, Hamburg, Helsinki, London, Rotterdam and Stockholm will grow from €230 to €1,530 billion. The highest damages are expected in London, Amsterdam and Rotterdam (European Commission, 2009e; EEA, 2008).

According to Bates et al. (2008), Central Europe will be prone to a rise in flood frequency. Particularly the Atlantic central zone will require improved defences and other preventive measures in the context of Integrated Coastal Zone Management plans (AEA, 2007).

Coastal flooding will also deeply affect the Mediterranean, where the IPCC predicts mounting damages from flooding and extreme events such as storm surges and tsunamis. Indeed, findings of the CIRCE project, which predicts and quantifies the physical impacts of climate change in the Mediterranean area, indicate that the expected rise in sea level will entail the submersion of low coastal areas, causing problems of groundwater salinisation (Magnan et al., 2009). The European Commission (2009a) asserts that under a scenario of a 0.5 m rise in the sea level by 2100 the population exposed to the risk of costal flooding will double in the region of Provence and in cities such as Athens, Naples, Lisbon, Porto and Barcelona. The loss of assets will also be considerable.

4. *Public water supply and drinking water*

Schröter et al. (2005), quoted in the IPCC's *Fourth Assessment Report*, maintain that by the 2070s the number of additional people living in water-stressed watersheds in the EU-15 (plus Switzerland and Norway) is likely to increase to between 16 and 44 million under the SRES A2 and B1[7] scenarios respectively, as projected by the HadCM3[8] model (+2.8°C and +3.1°C increase in Europe respectively by 2080) (Schröter et al., 2005 in IPCC, 2007b). Problems related to public water and drinking water will be exacerbated all over Europe with particular hotspots in the Mediterranean.

The Mediterranean will face problems of water scarcity more than any other region in Europe. Climate change may lead to an estimated decline in water availability, which will be greatest in the Mediterranean and southern Europe (European Commission, 2009a; MICE, 2005). Water availability may fall by 20-30% under a +2°C scenario and by 40-50% under a +4°C scenario. Summer water flows may be reduced by up to 80% and the annual average water runoff will decrease in Central and Eastern Europe and in the Mediterranean by 0-23% up to the 2020s and by 6-36% up to the 2070s (IPCC, 2007b).

Problems associated with water supply will affect the economy and the population, which will have to deal with increased droughts and water deficits on a daily basis. The agriculture and tourism sectors will be those affected most, above all on islands and in tourist resorts where problems of water supply are becoming ever more common. For example, Cyprus is exploring the possibilities of transporting water in tankers from Lebanon (EEA, 2008). Similar difficulties will be experienced in Central and Eastern Europe, where increased water stress and glacial retreat are projected.

In northern Europe, the impacts of climate change on water will vary across countries. Annual average runoff is projected to climb by approximately 5-15% up to the 2020s and 9-22% up to the 2070s for the SRES A2 and B2 scenarios (IPCC, 2007b). This will possibly be beneficial for agriculture and for public sources of water. Along the coasts, however, where coastal erosion will provoke water salinisation, there could be contamination of drinking water (Hilpert et al., 2007). On the other hand, for countries such as Ireland or England, where water is currently abundantly available, irrigation requirements are likely to become substantial because of increased water shortage (IPCC, 2007b). In south-east England, for example, foregone water use due to the anticipated water deficit may lead to economic losses to households in the magnitude of £41-388 million per year (EEA, 2008).

---

[7] The SRES B1 scenario describes a convergent world in terms of socio-economic development with global population that peaks in mid-century and declines thereafter, as in A1, but with a rapid change toward a service and information economy and the introduction of clean and resource-efficient technology, yet without additional climate initiatives. Concentrations of CO_2 increase to around 520 ppm in 2080.

[8] The Hadley Centre Coupled Model Version 3 (HadCM3) is a general circulation model (GCM) that was used by the ATEAM project to produce scenarios of climate change in Europe, including temperature and other physical impacts, under a number of SRES scenarios.

5. Crop yields in agriculture

The effects of climate change on agriculture and water will be quite different in the northern, southern and eastern regions of Europe, thus intensifying regional disparities. There may be some benefits and new opportunities, especially in northern Europe, but also many losses and additional difficulties for farmers in the south. Many studies give detailed information about the likely changes in agriculture.

Northern European agriculture will largely benefit from warmer temperatures, in terms of both crop yields and diversification. Productivity improvements in northern countries could reach 40-50% by the 2080s (Ciscar et al., 2009), with the largest increases in the hottest scenarios (i.e. +5.4°C). The reasons for productivity improvements in northern Europe are mainly related to prolonged growing seasons, higher minimum winter temperatures and an extension of the frost-free period. The AEA asserts that in the Atlantic and Boreal agro-climatic zones (especially in Estonia, Finland, Ireland, Latvia, Sweden and Scotland), there will be potential for cultivating new areas of crops and increasing yields due to longer growing seasons. Higher precipitation would also be taken advantage of by using crop varieties with a longer growing cycle by 2030–60 (Mechler et al., 2009). Moreover, some crops that are usually cultivated in the south (such as maize, sunflower and soybeans, starch crops and cereals) will grow in the north (IPCC, 2007b).

There will also be some adverse effects, however, such as a proliferation of pests and diseases. A greater frequency of extreme weather events is expected, including droughts along the Atlantic coast (e.g. Ireland), heavy storms and floods, owing to the higher intensity of precipitation, warmer temperatures and rising sea level – leading to soil salinisation and crop losses (European Commission, 2009d; AEA, 2007; PRUDENCE, 2005).

Impacts on Central and Eastern European agriculture, on the other hand, will generally be negative, although there are differences between and even within countries of that region. Initially, owing to warmer temperatures, the decrease in precipitation and the longer growing seasons, there may be an improvement in crop productivity (cereals, oilseeds and sugar beet) in countries such as Bulgaria, the Czech Republic, Hungary, Poland and Romania, (European Commission, 2009d; Stuzczynksi et al., 2000). Recent analysis for 2050 under the CLAVIER project predicts a positive climate-change effect on yields for the case study region in Bulgaria and a negative effect on the case study region in Romania (CLAVIER, 2009). The ADAM project predicts an overall negative effect on crop yields for Central and Eastern Europe in the period 2030–60 as a result of +2°C of global warming (Mechler et al., 2009). Results from the PESETA study (Ciscar et al., 2009) indicate higher losses in the northern parts of Central and Eastern Europe than in its southern parts, which can reach up to 8% in the 2080s compared with the 1961–90 period.

Mediterranean countries, where the agricultural sector is very important in terms of GDP and employment, will be hit the hardest and will experience the most negative development of natural conditions for crop cultivation, along with higher economic losses (European Commission, 2009d; EEA, 2008; MICE, 2005; Giannakopoulos et al., 2005).

Simulated changes in crop yields by the 2080s relative to the period 1961–90 show that the decrease in crop yields may reach almost 30% in Bulgaria, France, Greece, Italy and the Iberian Peninsula (Ciscar et al., 2009). The IPCC predicts general declines in yields (e.g. legumes -30 to +5%; sunflower -12 to +3% and tuber crops -14 to +7% by 2050) and increases in water demand (e.g. +2-4% for maize and +6-10% for potatoes by 2050) (AEA, 2007; IPCC, 2007b). Furthermore, research by the ATEAM project shows that the climate predicted under the HadCM3 A2 scenario (a +2.8°C increase in Europe) in many areas of southern Europe is envisaged to be less suitable for growing nearly all biofuel crops by 2050, and crops other than olives and those with a high temperature requirement and ability to withstand droughts (Schröter et al., 2004).

Falls in crop yields will be exacerbated by an increase in prolonged periods of droughts, a lack of water availability and a drop in precipitation incidence, which will in turn be much more intense. More frequent occurrences of extremes, such as dry spells and heat waves, will contribute as well (Mechler et al., 2009). Thus, Mediterranean countries need to invest in better irrigation systems, more balanced crop-rotation methods and crops better adapted to water and heat stress, and to maintain levels of soil organic matter (European Commission, 2009d).

Finally, Mediterranean countries, especially Greece, southern France, Italy and northern Spain, may experience an increase in the frequency and intensity of winter floods caused by significant rainfall. This would lead to a further decrease in crop yields and possibly to a build-up of soil salinity, which would narrow the choice of crops. Meanwhile, in northern Portugal and western France, there may be a greater risk of forest fires, affecting adjacent areas of permanent crops (AEA, 2007).

6. Crop yields in forestry

Forests in Europe will be affected by climate change, in terms of distribution, species composition, yields, storms and fires (EEA, 2008).

The forest area is expected to expand in northern Europe. Northern countries may therefore benefit significantly from an increase in growth rates and a northward expansion of forests. Especially in north-west Europe, where water supplies are abundant, growth rates are likely to be enhanced by a combination of rising carbon dioxide levels in the atmosphere, warmer winters and longer growing seasons (European Commission, 2008 and 2009e). For example, a study from Finland shows that the boosts in growth rates may be as high as 44% under the A2 scenario (European Commission, 2009a). Other consequences may include the alteration of species composition. For example, on its southern border, tundra will be replaced by coniferous boreal forest and scrublands. The reduction in tundra and associated permafrost will in turn lead to a reduction in the reflectance of solar radiation and may increase the incidence of wildfires (European Commission, 2009a). Nevertheless, as shown in the MICE project, the combination of raised mean temperature and a higher frequency of extreme events will have negative effects that could ultimately be of greater importance than the positive outcomes of a warmer climate. The boreal forests for example, may be severely affected by summer dry spells and droughts, making trees more susceptible to frost damage, windthrow, storms and attacks by pests and diseases (MICE, 2005).

In Central Europe, there will be changes in the forest species composition. Indeed, the native conifer could be replaced by deciduous trees or broadleaved species (Maracchi et al., 2005 and Koca et al., 2006 in IPCC, 2007b).

In the south, forests will generally contract and species with southern habitats will be those most affected. In particular, more frequent and severe summer droughts are likely to lead to reduced productivity, more extensive forest fires and, ultimately, desertification in some areas (European Commission, 2009a and 2008; Schröter et al., 2004).

7. Biodiversity

Biodiversity loss will be an advancing threat for Europe under climate change, and will cause significant welfare losses owing to ecosystem degradation. Current modelling techniques do not include all the factors affecting biodiversity, and the rates of species loss and turnover show great variation across scenarios. Therefore, the results of the studies need to be analysed critically, taking into account the uncertainty of predictions and the high regional variability. Despite these uncertainties and that only a few extinctions have yet been observed, larger impacts are expected in the near future (MACIS, 2008).

In northern Europe, some arctic and alpine species will disappear but the range of plants is very likely to expand northward and invasive species will find a better habitat in which to grow. The boreal region for example, could in principle gain many species from the south, leading to a high species turnover (Thuiller et al., 2005). Meanwhile, a sea-level rise will reduce habitat availability for bird species that nest or forage in low-lying coastal areas. This consequence is particularly important for the populations of shorebirds that breed in the Arctic and then winter on European coasts (Rehfisch & Crick, 2003; IPCC, 2007b). Freshwater species are also going to be affected by climate warming and they will shift their ranges to higher latitudes and altitudes. With regard to terrestrial mammal species, they will extend towards the north-eastern and mountainous areas such as the Alps and Pyrenees, assuming that movement through fragmented landscapes is possible, whereas in polar regions, projected reductions in sea ice will drastically reduce the habitat for polar bears, seals and other ice-dependent species (IPCC, 2007b). Similarly, the MONARCH project, which provides an overview of the potential ramifications of climate change on species distribution in England and Ireland, registers a northward shift in climate species and a range extension in northern Europe (Berry et al., 2007).

Biodiversity will diminish in Central Europe, moving northwards because of climate warming. In Austria for example, higher temperatures are forecast to erode the depth of snow cover and reduce biodiversity. The distribution of land use will change as the distribution of species in mountainous areas may shift upwards (AEA, 2007).

Mediterranean biodiversity/ecosystems are also vulnerable and predicted to suffer from water scarcity and heat stress because of temperatures above the heat comfort zone (EEA, 2008; AEA, 2007). This is expected to result in an increased frequency of forest mortality events, which will affect forest diversity, as suggested by the ALARM project (Peñuelas et al., 2009).

Plant species losses of up to 62% are projected for the southern regions, particularly in the mountains where there may be a loss of endemism owing to invasive species as well as a loss in plant range (IPCC, 2007b). The alpine climatic zone has been projected to climb by 500 m by 2085 under certain ATEAM scenarios, leading to a 40-fold reduction of its area in an example for the Pyrenees, with profound changes to existing habitats and consequent effects on the flora and fauna there (Nagy et al., 2009). In some areas such as north central Spain, the Cavennes and the Massif Central in France, the percentage of species loss could even exceed 80% (Thuiller et al., 2005). Profound changes may also occur at the ecosystem level. The gradual rise in terrestrial and marine temperatures will cause the modification of natural habitats, which in the Mediterranean are already subject to intense pressures, and a massive loss of biodiversity (Magnan et al., 2009).

An assessment of European fauna indicates that the majority of amphibian (45-69%) and reptile (61-89%) species could expand their range under various SRES scenarios but since dispersion is very likely to be limited, it is more probable that the range of most species (>97%) would contract, especially in the Iberian Peninsula, France and parts of Italy (IPCC, 2007b). But for example, the cold-adapted species in the Alps are being displaced as the lower altitude species move uphill because of changes in the Alps' climate.

8. Energy for heating and cooling

Climate change will affect the energy sector not just through its effects on energy production (see indicator category 9), but also through related changes in demand patterns. Changes will differ according to each region's climatic conditions. While demand for heating in winter may go down, demand for summer cooling may step up (EEA, 2008). The net effect on energy demand could be negative, as increases in electricity demand for cooling are likely to be outweighed by reductions in the need for heating energy. Yet, as noted by Eskeland et al. (2008), electricity required for cooling is far more carbon-intensive than energy used for heating. Depending on the final energy mix of the electricity supply in member states, net CO_2 emissions could even rise.

The results of the ADAM project (based on the POLES model) show that final energy demand could fall by 3.3% in 2050 compared with 2005 under their +4°C reference scenario[9] (Jochem & Schade, 2009). The sectoral analysis reveals that it is the residential sector that makes the biggest contribution to this savings (-10%). In terms of geography, the largest decreases are in western Europe (-4.3%) and in Central and Eastern Europe (-3.8%). Demand for electricity, on the other hand, is expected to grow by 1.7% until 2050 compared with 2005 under the +4°C scenario. In southern Europe, electricity demand would increase by almost 5%, while decreasing in the north by 0.5% (ibid.).

Northern Europe will be able to significantly reduce the consumption of winter heating, compared with the current high level of consumption. In Finland for example, winter heating demand is estimated to fall by 10% between 2021 and 2050, and by 20-30% by 2100 (Kirkinen et al., 2005; Venalainen et al., 2004 in IPCC, 2007b). With a 2°C temperature rise by 2050, heating requirements in winter will fall in the UK as well, thus cutting fossil fuel demand by 5-10% and electricity demand by 1-3%, (Kirkinen et al., 2005 in IPCC, 2007b). The use of summer cooling will increase, however. In London for instance, the typical air-conditioned office building is estimated to increase the energy used for cooling by 10% by the 2050s and by around 20% by the 2080s (LCCP, 2002 in EEA, 2008). As mentioned above, in the ADAM reference scenario, final energy demand in northern Europe is projected to decline by between 2% (in the northern parts) and 4.3% (in the western parts) by 2050. Electricity demand is expected to decrease by 0.5% in the northern parts, while it may increase by 0.5% in the western parts[10] (Jochem & Schade, 2009).

Similar impacts may be registered in Central and Eastern Europe. With the exception of the southern parts of the region (e.g. Bulgaria and France), under the ADAM reference scenario final energy demand declines in 2050 by more than 3%, while electricity demand increases by only 0.7% (Jochem & Schade, 2009). Demand for winter heating will generally lessen, such as in Hungary and Romania, where it is estimated to fall by 6-8% by the period 2021 to 2050 (Vajda et al., 2004 in IPCC, 2007b).

In contrast, Mediterranean countries will have a severe problem related to the demand for summer cooling. Demand for cooling is likely to rise significantly (European Commission, 2009a and 2009e), with an estimated increase in electricity demand of around 5% under the ADAM reference scenario in 2050.

Giannakopoulos et al. (2005) estimate that the Mediterranean will need fewer weeks (two to three) a year of heating but an additional two to five weeks of cooling by 2050. Cartalis et al. (2001) and Fronzek & Carter (2007) project a decrease in energy heating requirements of up to 10% but a strong increase in cooling requirements of up to 28%, reaching some 114% in Madrid. These outcomes are also associated with an increase in intra-annual variability by 2071 to 2100 (IPCC, 2007b; EEA, 2008). Overall, however, the energy demand in southern Europe is

[9] This scenario entails a +4°C increase of global average temperature above pre-industrial levels.

[10] The ADAM project divides Europe into four regions (north, west, central-east and south), which differs from the division in our study. Therefore, we have used an approximation.

still expected to decline but only by -1.7% under the ADAM reference scenario by 2050 (Jochem & Schade, 2009).

Consequent peaks in electricity demand to respond to the needs of summer space cooling are very likely to increase, up to 50% in Italy and Spain, and 30% in Greece by the 2080s (Livermore, 2005 and Giannakopoulos et al., 2005 in IPCC, 2007b). They are also likely to exceed the peaks in demand for heating during cold winter periods, e.g. in Spain (López Zafra et al., 2005 in IPCC, 2007b).

9. Hydropower and cooling for thermal plants

According to the EEA, the hydropower sector will be affected by climate change, as the production of electricity is highly dependent on water. Some areas may benefit from increased precipitation, melting glaciers and thus run-off water while others will suffer from decreases (EEA, 2008; Jochem & Schade, 2009).

Northern Europe may benefit from an increase in river run-off (see also indicator category 4 above). Additional precipitation will especially benefit Belgium, the Netherlands and the UK, as well as the Baltic and Nordic states. The hydropower potential in northern Europe is hence expected to grow by more than 25% by 2050 (Jochem & Schade, 2009) and up to 30% by the 2070s (IPCC, 2007b). The Nordic Climate and Energy study (covering Scandinavia, Iceland and the Baltic states) (Bergström et al., 2007, cited in EEA, 2008) projects that the largest increases will be in the western coastal regions and it registers increases in hydropower production in Scandinavia.

In contrast, the Mediterranean and even Central and Eastern Europe may experience a decrease in hydropower potential of around 25% by 2050 (Jochem & Schade, 2009) and up to 50% by the 2070s (IPCC, 2007b). Indeed, hydropower potential is likely to suffer from reduced annual precipitation, especially in winter (Jochem & Schade, 2009), due to changing climate patterns, except in the Alps and in Portugal where run-off water may expand the potential for hydroelectricity generation (European Commission, 2009a). At the same time, Alpine run-off is subject to greater intra-annual variability as summers grow hotter (Hauenstein, 2005, cited in Jochem & Schade, 2009).

The cooling systems of thermal power plants (i.e. almost all coal, nuclear, geothermal, solar thermal electric and waste incineration plants, as well as many natural gas power plants) will be affected by the increasing temperatures of the atmosphere and rivers. Extreme heat waves can pose a serious threat to uninterrupted electricity supplies, mainly because cooling air may be too warm and cooling water may be both scarce and too warm. This can result in reduced capacities and reduced efficiency rates. The efficiencies mainly result from higher power demand for pumps to maintain desired condensing temperatures, as well as the change from wet to dry cooling towers (European Commission, 2009e; Eskeland et al., 2008).

As regards other sources of energy, Eskeland et al. (2008) note that higher temperatures and atmospheric CO_2 concentrations in moderate climates north of the Alps may benefit the growth of biomass and thus the electricity generation from agricultural crops, manure and wood chips. Similarly, accelerating average wind velocities could improve the electricity output of wind converters. On the other hand, the efficiency of photovoltaic plants could be slightly reduced by higher temperatures, especially during heat waves. Finally, brownouts and blackouts stemming from storms, floods and heat waves may lead to more decentralised electricity generation in order to avoid the impacts of interruptions in supply for certain electricity users.

10. *Tourism and recreation*

Changes in climate are already affecting the tourist sector and some tourism resorts in Europe, especially in the Mediterranean and in the Alps. In the future, these effects will be exacerbated. Yet, not all the results for tourism would be negative. Northern regions may benefit from milder winters and warmer temperatures in summer, while the Mediterranean summer season will be severely compromised by heat waves and droughts.

Hamilton et al. (2005) indicate that an arbitrary climate-change scenario of +1°C could lead to a gradual shift of tourist destinations further north and up mountains, where outdoor activities would become more attractive, affecting summer tourism on the Mediterranean beaches (EEA, 2008; European Commission, 2009a; IPCC, 2007b). Studies from the MICE project also suggest that warmer temperatures in the north will benefit the tourism sector. According to the PESETA study, northern Europe will benefit the most among all European regions, adding to the number of bed nights by 4-25% until the 2080s, compared with the 1970s (the numbers refer to the +2.5°C scenario and the +5.4°C scenario, respectively) (Ciscar et al., 2009). To give an illustration, the abnormally warm and dry year of 1995 in the UK benefited the tourist industry by an estimated £309 million relative to average years (MICE, 2005). But traditional summer destinations like the Mediterranean or winter destinations such as mountainous regions are likely to suffer from a decline in tourism in the longer term because of worsening weather and climatic conditions (European Commission, 2009e).

In Central Europe, the aspect of tourism that will be most affected is skiing, through significant reductions in natural snow cover, especially at the beginning and end of the skiing season (Elsasser & Burki, 2002). The winter tourism industry provides a significant contribution to the economy of the countries concerned. For many of the Alpine areas of Switzerland for example, winter tourism represents the most important source of income and enables the regional economic growth of these rural mountainous areas. Similarly, the winter tourism industry accounts for 4.5% of Austrian GNP (Agrawala, 2007). Different studies reviewed by the IPCC found that at the most sensitive elevation in the Austrian Alps (600 m in winter and 1,400 m in spring) and with no snowmaking adaptation considered, a 1°C temperature rise leads to four fewer weeks of skiing in winter and six fewer weeks in spring. Similarly, 2°C of warming with no precipitation change would reduce the seasonal snow cover in a Swiss Alpine site by 50 days per year. This is clearly detrimental for skiing resorts and for winter tourism, especially in Austria, France, Germany, Italy and Switzerland (Hantel et al., 2000; Beniston et al., 2003 in EEA, 2008; Agrawala, 2007, which may increasingly need to shift their focus to summer holidays.

It should be noted, however, that apart from skiing-related tourism, Central and Eastern European tourism as a whole could benefit from climate change. As indicated by the results of the PESETA study, the number of annual bed nights could increase by 2-17% until the 2080s compared with the 1970s (Ciscar et al., 2009). This may stem from dryer summers with higher temperatures (European Commission, 2009e).

Similar to Central and Eastern Europe, winter tourism in the Mediterranean Alps will also diminish due to a reduction in snow areas. The IPCC predicts that in the Alps the number of snow-reliable areas (with adequate snow cover for at least 100 days per year) under a 2°C increase scenario would be reduced from the current 600 to 400, and to 200 under a 4°C scenario (IPCC, 2007b). These regions, especially the mountainous parts of France, Italy and Spain, could perhaps expand tourism in the shoulder seasons and summer but there will still be a great loss of revenues. Higher temperatures will have the worst impact on the Mediterranean costal zones, which will see a drastic reduction of tourism owing to heat waves and water supply problems in many tourist resorts (Giannakopoulos et al., 2005). Tourism could pick up in the spring and autumn, but if there is no adjustment and redistribution or seasonal shift away from the summer peaks, the Mediterranean tourist sector will see decreasing bed nights in Europe (European Commission, 2009a; EEA, 2008). According to the PESETA study, southern Europe will lose some 1-4% of bed nights by the 2080s compared with the 1970s (Ciscar et al., 2009).

11. Health

Modelling and assessing the impacts of climate change on human health are characterised by a high degree of uncertainty. Nonetheless, most studies indicate an increase in the heat-related mortality rate while the number of deaths attributable to cold weather could decrease. Similarly, vector-borne diseases such as malaria or dengue fever could spread in European regions, and at higher altitudes. Like most other effects, those on health are unevenly distributed across Europe, with Central and Eastern Europe likely to experience the highest rise in heat-related deaths (in absolute terms). Cold-related deaths are likely to fall the most in the British Isles and in southern Europe (Ciscar et al., 2009). The PESETA study also found that in the short term (i.e. until the 2020s), the net effect would be positive with reductions in cold-related deaths outweighing increases in heat-related ones. In the long term (i.e. until the 2080s), the net results are less clear, depending on the set of exposure-response and acclimatisation functions used (ibid.).

Like everywhere else in Europe, climate change will have a twofold impact on northern Europe. On the one hand, cold-related deaths will decline, while on the other hand the annual heat-related deaths in summer are expected to escalate. In the UK, for instance, annual cold-related deaths are expected to fall from about 80,300 in the 1990s to about 60,000 in the 2050s and 51,200 in the 2080s in the medium-high climate and population scenario. But deaths from excessive heat are projected to rise from about 800 in the 1990s to about 2,800 in the 2050s and about 3,500 in the 2080s under the same scenario (Donaldson et al., 2001 in EEA, 2008). According to the cCASHh study, which investigates climate change and adaptation strategies for human health in Europe, not only heat waves and floods are detrimental for human health. Food- and vector-borne diseases can also pose a danger. These are indirect effects of climate change through alterations in the seasonal patterns of diseases. Milder temperatures in northern Europe in combination with higher rainfalls could indeed increase the possibility of food- and vector-borne diseases. For instance, cCASHh results have shown that the largely tick-transmitted Lyme borreliosis and tick-borne encephalitis have spread into higher latitudes (e.g. in Sweden) and altitudes (e.g. in the Czech Republic) in recent decades, and that their transmission season will be extended and more intense in the future (WHO, 2005). Similarly, the risk of local malaria transmission could spread in northern Europe (e.g. by 8-15% in the UK, according to EEA, 2008).

In central European regions, climate change will generally decrease the mortality rate related to cold weather conditions, leading to a short-term improvement in the quality of life over approximately the next 15 years. In the longer run, however, the impacts of climate change will be negative and the quality of life will decline (European Commission, 2009e). For example, in Germany, projections show a 20% increase in heat-related deaths in the 2080s compared with the 1980s, which is not likely to be compensated by reductions in the number cold-related ones (Koppe et al., 2003 in EEA, 2008). Furthermore, although there is agreement that the risk of a potential spread of malaria in Europe is very low under current socio-economic conditions, some Eastern European countries might be at risk. In Eastern European countries, where per-capita health expenditure is relatively low, health services are less efficient in detecting and treating malaria cases, and the environmental measures to control mosquito distribution are poorly implemented. This could eventually contribute to the uncontrolled spread of the disease in these countries (WHO, 2005).

The Mediterranean countries appear to be those most affected in terms of human health issues. Mortality rates will be much greater in southern and south-eastern Europe, particularly in areas such as Greece and Portugal, due to the greater warming trend in these regions (European Commission, 2009a; WHO, 2005). The rise in temperature, heat waves and summer peaks will add dramatically to heat-related deaths, especially among the eldest. Considering the ageing of the population this might be a severe problem for the Mediterranean. The IPCC projects increases in heat-related mortalities from a baseline of 5.4-6 per 100,000 to a range of 19.5-248 per 100,000 by the 2080s, and in the number of days suitable for the survival of malaria vectors (IPCC, 2007b). Furthermore, the risk of additional salmonella problems from bathing water quality is likely to grow (EEA, 2008).

Conclusions

This study gives an overview of the climate change impacts on three large European regions. It represents a literature review aimed at a largely qualitative assessment of these impacts on 11 indicators. One conclusion to be drawn is that there remains a lot of uncertainty about local and regional effects, as evident from the wide range of some of the projected results. Still, even at currently high levels of uncertainty, it is clear that the repercussions will vary considerably across regions. Some effects could even benefit certain regions. Most of the positive impacts will be in northern Europe. This region could benefit from higher crop yields, an expansion of forest areas and enhanced forest-growth rates, an increasing number of tourist visits, and a net decrease in climate-related deaths.

While northern Europe will also have to bear some severe negative consequences (e.g. in the form of more frequent extreme weather events or coastal and river flooding), it is mainly the countries in the south, which are already economically disadvantaged, that will suffer most. Some of the most severe negative impacts in the Mediterranean include prolonged periods with temperatures above the comfort zone and the accompanying effects on human health and tourism, increasing water scarcity, droughts, forest fires, desertification, decreasing agricultural productivity, coastal flooding and loss of biodiversity. One of the few positive outcomes will be the reduced likelihood of river flood disasters (which will be more frequent in Central and Eastern Europe).

The outlined future impacts of climate change on the EU are a useful starting point for policy-makers when shaping effective adaptation policies for Europe. Uncertainties, variability and differences among estimates remain. Nevertheless, while the precise quantification of the economic consequences requires continuing research and may be impossible even at a later stage, the nature of the possible impacts and the geographical and sectoral differentiation appear to be sufficiently clear at this stage. The magnitude of the effects depends on the global emissions pathways, but it has been possible to approximate it from existing global mitigation efforts and it can be adjusted as the effects evolve.

The results of this study clearly illustrate strong distributional patterns. Similar to the global context, where poorer developing countries are expected to suffer most, it is the poor regions in Europe that will be affected most. Hence, climate change further compounds the difficulties of these countries in achieving a level of welfare equivalent to the EU average. At the same time, the cumulative impacts of climate change on poorer countries will also affect northern European countries, as growing water scarcity and other repercussions in Mediterranean countries could pose social and security challenges through increasing risks of conflicts and migration pressures. Fighting climate change through domestic and international action is thus not only a matter of solidarity, but clearly in the self-interest of the EU and *all* of its member states.

Bibliography

Aaheim, A., F. Berkhout, D. McEvoy, R. Mechler, H. Neufeldt, A. Patt, P. Watkiss, A. Wreford, Z. Kundzewicz, C. Lavalle and C. Egenhofer (2008), *Adaptation to Climate Change: Why is it needed and how can it be implemented?*, CEPS Policy Brief No. 161, ADAM/CEPS, Brussels, May.

Agrawala, S. (ed.) (2007), *Climate Change in the European Alps: Adapting Winter Tourism and Natural Hazards Management*, OECD, Paris.

Atomic Energy Authority (AEA) (2007), *Adaptation to Climate Change in the Agricultural Sector*, AGRI-2006-G4-05, AEA Energy & Environment and Universidad de Politécnica de Madrid.

Bates, B.C., Z.W. Kundzewicz, S. Wu and J.P. Palutikof (eds) (2008), *Climate Change and Water*, IPCC Technical Paper, IPCC Secretariat, Geneva, June.

Beniston, M., F. Keller and S. Goyette (2003), "Snow pack in the Swiss Alps under changing climatic conditions: An empirical approach for climate impact studies", *Theoretical and Applied Climatology*, Vol. 74, Nos. 1-2, pp. 19–31.

Bergström, S., T. Jóhannesson, G. Aðalgeirsdóttir, A. Ahlstrøm, L.M. Andreassen, J. Andréasson, S. Beldring, H. Björnsson, B. Carlsson, P. Crochet, M. de Woul, B. Einarsson, H. Elvehøy, G.E. Flowers, P. Graham, G.O. Gröndal, S. Guðmundsson, S.-S. Hellström, R. Hock, P. Holmlund, J.F. Jónsdóttir, F. Pálsson, V. Radoc, N. Reeh, L.A. Roald, S. Rogozova, J. Rosberg, O. Sigurðsson, M. Suomalainen, T. Thorsteinsson, B. Vehviläinen and N. Veijalainen (2007), *Impacts of climate change on river runoff, glaciers and hydropower in the Nordic area*, Joint final report from the CE Hydrological Models and Snow and Ice Groups, CE Report CE-6, Norden–Nordic Energy Research, Reykjavik.

Berry, P.M., J.R. O'Hanley, C.L. Thomson, P.A Harrisson, G.J. Masters and T.P. Dawson (eds) (2007), *MONARCH 3*, Full technical report, UK Climate Impacts Programme, Oxford, January (http://www.ukcip.org.uk/index.php?option=com_content&task=view&id=331).

Bugmann, H.K.M., B. Zierl and S. Schumacher (2005), "Projecting the Impacts of Climate Change on Mountain Forests and Landscapes", in U.M. Huber, H.K.M. Bugmann and M.A. Reasoner (eds), *Global Change and Mountain Regions*, Dordrecht: Springer Netherlands, pp. 477–87.

Cartalis, C., A. Synodinou, M. Proedrou, A. Tsangrassoulis and M. Santamouris (2001), "Modifications in energy demand in urban areas as a result of climate changes: An assessment for the southeast Mediterranean region", *Energy Conversion and Management*, Vol. 42, No. 14, pp. 1647–56.

Ciscar, J.-C. (ed.), A. Soria, C.M. Goodess, O.B. Christensen, A. Iglesias, L. Garrote, M. Moneo, M. Moreno, A. Pye, S. Quiroga and S. van Regemorter (2009), *Climate change impacts in Europe: Final report of the PESETA research project*, Joint Research Centre Scientific and Technical Report (EUR 24093 EN), European Commission, Luxembourg: Office for Official Publications of the European Communities, November.

CLAVIER (2009), "Results in WP4: Economic Vulnerability of CEE Societies and Economic Impact Assessment", CLAVIER Project (coordinator: Max Planck Institute for Meteorology) (http://www.clavier-eu.org/?q=node/881).

Donaldson, G., R.S. Kovats, W.R. Keatinge and R.J. McMichael (2001), "Heat- and cold-related mortality and morbidity and climate change", in *Health effects of climate change in the UK*, Expert Group on Climate Change and Health, UK Department of Health, London, pp. 70–80.

Elsasser, H. and R. Burki (2002), "Climate change as a threat to tourism in the Alps", *Climate Research*, Vol. 20, pp. 253–57.

Eskeland, G., E. Jochem, H. Neufeldt, T. Traber, N. Rive and A. Behrens (2008), *The Future of European Electricity Choices before 2020*, ADAM/CEPS Policy Brief No. 164, CEPS, Brussels, July.

European Commission (2008), *Regions 2020: An Assessment of Future Challenges for EU Regions*, Commission Staff Working Document SEC(2008) 2868 final, Directorate-General for Regional Policy, Brussels, November.

————— (2009a), *Impact Assessment*, Commission Staff Working Document accompanying the White Paper on Adapting to Climate Change: Towards a European Framework for Action (COM(2009, 147 final), SEC(2009) 387/2, Brussels.

————— (2009b), *Climate Change and Water, Coasts and Marine Issues*, Commission Staff Working Document accompanying the White Paper on Adapting to Climate Change: Towards a European Framework for Action (COM(2009, 147 final), SEC(2009) 0386 final, Brussels.

————— (2009c), "*Human, Animal and Plant Health Impacts of Climate Change*", Commission Staff Working Document, accompanying document to the White Paper on Adapting to Climate Change: Towards a European Framework for Action (COM(2009, 147 final), SEC(2009) 416, Brussels.

————— (2009d), *Adapting to Climate change: The Challenge for European Agriculture and Rural Areas*, Commission Staff Working Document accompanying the White Paper on Adapting to Climate Change: Towards a European Framework for Action (COM(2009, 147 final), SEC(2009) 417, Brussels.

————— (2009e), *Regions 2020: The Climate Change Challenge for European Regions*, background document to Commission Staff Working Document, *Regions 2020: An Assessment of Future Challenges for EU regions* (SEC(2008) 2868 final), Directorate-General for Regional Policy, Brussels, March.

European Environment Agency (EEA) (2008), *Impacts of Europe's changing climate – 2008 indicator-based assessment*, EEA Report No. 4/2008, EEA, Copenhagen, October.

Fronzek, S. and T.R. Carter (2007), "Assessing uncertainties in climate change impacts on resource potential for Europe based on projections from RCMs and GCMs", *Climatic Change*, Vol. 81, Suppl. 1, pp. 357–71.

Giannakopoulos, C., M. Bindi, M. Moriondo, P. LeSager and T. Tin (2005), *Climate Change Impacts in the Mediterranean Resulting from a 2^{o}C Global Temperature Rise*, WWF report, WWF, Gland, Switzerland (http://assets.panda.org/downloads/medreportfinal8july05.pdf).

Gobiet, A. and the WegCenter-ReLoClim Team (2009), "Regionalisation of Climate Scenarios for Climate Change Impact and Adaptation Research", presentation at the International Conference on The Economics of Adaptation to Climate Change, ZEW, Mannheim, 16-17 June.

Hallegatte, S., J.-C. Hourcade and P. Ambrosi (2007), "Using Climate Analogues for Assessing Climate Change Economic Impacts in Urban Areas", *Climatic Change*, Vol. 82, Nos. 1-2, pp. 47–60.

Hamilton, J.M., D.J. Maddison and R.S.J. Tol (2005), "Climate change and international tourism: A simulation study", *Global Environmental Change*, Vol. 15, No. 3, pp. 253–66.

Hantel, M., M. Ehrendorfer and A. Haslinger (2000), "Climate sensitivity of snow cover duration in Austria", *International Journal of Climatology*, Vol. 20, No. 6, pp. 615–40.

Hauenstein, W. (2005), "Hydropower and climate change – A reciprocal relation: Institutional energy issues in Switzerland", *Mountain Research and Development*, Vol. 25, No. 4, pp. 321–25.

Hilpert, K., F. Mannke and P. Schmidt-Thomé (2007), *Towards Climate Change Adaptation in the Baltic Sea Region (ASTRA)*, Geological Survey of Finland, Espoo (http://www.astra-project.org/).

Intergovernmental Panel on Climate Change (IPCC) (2000), *Emissions Scenarios*, Special Report of Working Group III of the Intergovernmental Panel on Climate Change, Cambridge: Cambridge University Press.

———— (2007a), "Climate Change 2007: The Physical Science Basis", Working Group I Contribution to the *Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge: Cambridge University Press.

———— (2007b), "Climate Change 2007 – Impacts, Adaptation and Vulnerability", Working Group II Contribution to the *Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge: Cambridge University Press.

Jacob, D., O. Christensen, F. Doblas-Reyes, C. Goodess, A.K. Tank, P. Lorenz and E. Roeckner (2008), *ENSEMBLES Technical Report No. 4: Information on observations, global and regional modelling data availability and statistical downscaling*, ENSEMBLES Project, May.

Jochem, E. and W. Schade (2009), *Adaptation and Mitigation Strategies Supporting European Climate Policy*, ADAM Deliverable D-M1.2, Fraunhofer Institute for Systems and Innovation Research, Munich, May.

Kirkinen, J., A. Matrikainen, H. Holttinen, I. Savolainen, O. Auvinen and S. Syri (2005), *Impacts on the Energy Sector and Adaptation of the Electricity Network under a Changing Climate in Finland, FINADAPT*, Working Paper No. 10, Finnish Environment Institute, Helsinki.

Kjellström, E., L. Bärring, D. Jacob, R. Jones, G. Lenderink and C. Schär (2007), "Modelling daily temperature extremes: Recent climate and future changes over Europe", *Climatic Change*, Vol. 81, Suppl., pp. 249–65.

Koca, D., S. Smith and M.T. Sykes (2006), "Modelling regional climate change effects on potential natural ecosystems in Sweden", *Climatic Change*, Vol. 78, Nos. 2-4, pp. 381–406.

Koppe, C., S. Kovats, G. Jendritzky and B. Menne (2004), *Heat waves: Risks and responses,* Health and Global Environmental Change Series, No. 2, WHO Regional Office for Europe, Copenhagen.

Leckebusch, G.C., U. Ulbrich, L. Fröhlich and J.G. Pinto (2007), "Property loss potentials for European mid-latitude storms in a changing climate", *Geophysical Research Letters*, Vol. 34, No. 5.

Lenderink, G., A. van Ulden, B. van den Hurk and E. van Meijgaard (2007), "Summertime inter-annual temperature variability in an ensemble of regional model simulations: Analysis of the surface energy budget", *Climatic Change*, Vol. 81, Suppl., pp. 233–47.

Maddison, D. (2001), "In search of warmer climates? The impact of climate change on flows of British tourists", *Climatic Change*, Vol. 49, Nos. 1-2, pp. 193–208.

Livermore, M.T.J. (2005), "The Potential Impacts of Climate Change in Europe: The Role of Extreme Temperatures", PhD thesis, University of East Anglia, Norwich.

London Climate Change Partnership (LCCP) (2002), *London's Warming: The Impacts of Climate Change on London*, Technical report, Greater London Authority, London (http://www.london.gov.uk/lccp/publications/impacts.jsp).

López Zafra, J.M., L. Sánchez de Tembleque and V. Meneu (2005), "Impactos sobre el sector energético", in J.M. Moreno (ed.), *Evaluación Preliminar de los Impactos en España for Efecto del Cambio Climático*, Ministerio de Medio Ambiente, Madrid, pp. 617–52.

MACIS (2008), *Deliverable 1.1: Climate change impacts on European biodiversity – Observations and future projections*, MACIS Project, April (www.macis-project.net).

Magnan, A., B. Garnaud, R. Billé, F. Gemenne and S. Hallegatte (2009), *The future of the Mediterranean: From impacts of climate change to adaptation issues*, IDDRI, Paris, May.

Maracchi, G., O. Sirotenko and M. Bindi (2005), "Impacts of present and future climate variability on agriculture and forestry in the temperate regions: Europe", *Climatic Change*, Vol. 70, Nos. 1-2, pp. 117–35.

Mechler, R., S. Hochrainer, A. Aaheim, Z. Kundzewicz, N. Lugeri, M. Moriondo, H. Salen, M. Bindi, I. Banaszak, A. Chorynski, E. Genovese, H. Kalirai, J. Linnerooth-Bayer, C. Lavalle, D. McEvoy, P. Matczak, M. Radziejewski, D. Rübbelke, M.-J. Schelhaas, M. Szwed and A. Wreford (2009), "A risk management approach for assessing adaptation to changing flood and drought risks in Europe", in M. Hulme and H. Neufeldt (eds), *Making Climate Change Work for Us: European Perspectives on Adaptation and Mitigation Strategies*, Cambridge: Cambridge University Press.

Menne, B. and K.L. Kristie (eds) (2006), *Climate change and adaptation strategies for human health*, Darmstadt: Steinkopff Verlag.

MICE (2005), *MICE Summary of Final Report*, MICE Team, MICE Project, August (http://www.cru.uea.ac.uk/cru/projects/mice/html/reports.html).

Nagy, L., H. Pauli, M. Gottfried and G. Grabherr (2009), "Climate Change Impact on the Future Extent of the Alpine Climate Zone", in J. Settele, L. Penev, T. Georgiev, R. Grabaum, V. Grobelnik, V. Hammen, S. Klotz and I. Kühn (eds), *Atlas of Biodiversity Risk*, Sofia and Moscow: Pensoft Publishers.

Patz, J.A., D. Campbell-Lendrum, T. Holloway and J.A. Foley (2005), "Impact of Regional Climate Change on Human Health", *Nature,* Vol. 438, No. 7066, pp. 310–17.

Peñuelas, J., M. Estiarte, P. Prieto, J. Sardans, A. Jump, J.M. Moreno, I. Torres, B. Céspedes, E. Pla, S. Sabaté and C. Gracia (2009), "Projected Climate Change Impacts on Biodiversity in Mediterranean Ecosystems", in J. Settele, L. Penev, T. Georgiev, R. Grabaum, V. Grobelnik, V. Hammen, S. Klotz and I. Kühn (eds), *Atlas of Biodiversity Risk*, Sofia and Moscow: Pensoft Publishers.

PRUDENCE (2005), *Prediction of Regional Scenarios and Uncertainties for Defining European Climate Change Risks and Effects*, Final Report, EVK2-CT2001-00132, PRUDENCE Project, February (http://prudence.dmi.dk).

Rehdanz, K. and D. Maddison (2005), "Climate and Happiness", *Ecological Economics*, Vol. 52, No. 1, pp. 111–25.

Rehfisch, M.M. and H.Q.P. Crick (2003), "Predicting the impact of climatic change on Arctic breeding waders", *Wader Study Group Bulletin*, No. 100, pp. 86–95.

Rodríguez-Fonseca, B., E. Sánchez and A. Arribas (2005), "Winter climate variability changes over Europe and the Mediterranean region under increased greenhouse conditions", *Geophysical Research Letters*, Vol. 32, No. 13.

Scherrer, S.C., C. Appenzeller, M.A. Liniger and C. Schär (2005), "European temperature distribution changes in observations and climate change scenarios", *Geophysical Research Letters*, Vol. 32, No. 19.

Schröter, D., L. Acosta-Michlik, A.W. Arnell, M.B. Araújo, F. Badeck, M. Bakker, A. Bondeau, H. Bugmann, T. Carter, A.C. de la Vega-Leinert, M. Erhard, G.Z. Espiñeira, F. Ewert, U. Fritsch, P. Friedlingstein, M. Glendining, C.A. Gracia, T. Hickler, J. House, M. Hulme, S. Kankaanpää, R.J.T. Klein, B. Krukenberg, S. Lavorel, R. Leemans, M. Lindner, J. Liski, M.J. Metzger, J. Meyer, T. Mitchell, F. Mohren, P. Morales, J.M. Moreno, I. Reginster, P. Reidsma, M. Rounsevell, E. Pla, J. Pluimers, I.C. Prentice, A. Pussinen, A. Sánchez, S. Sabaté, S. Sitch, B. Smith, J. Smith, P. Smith, M.T. Sykes, K. Thonicke, W. Thuiller, G. Tuck, G. van der Werf, J. Vayreda, M. Wattenbach, D.W. Wilson, F.I. Woodward, S. Zaehle, B. Zierl, S. Zudin and W. Cramer (2004), *ATEAM Final report 2004: Section 5 and 6*, Potsdam Institute for Climate Impact Research, Potsdam (www.pik-potsdam.de/ateam).

Schröter, D., W. Cramer, R. Leemans, I.C. Prentice, M.B. Araújo, N.W. Arnell, A. Bondeau, Bugmann, T.R. Carter, C.A. Gracia, A.C. de la Vega-Leinert and M. Erhard (2005), "Ecosystem Service Supply and Vulnerability to Global Change in Europe", *Science*, Vol. 310, No. 5752, pp. 1333–37, November.

Seneviratne, S.I., D. Lüthi, M. Litschi and C. Schär (2006), "Land–atmosphere coupling and climate change in Europe", *Nature*, Vol. 443, No. 7108, pp. 205–09.

STARDEX (2005), *The Stardex Final Report – Downscaling climate extremes*, STARDEX Project (http://www.cru.uea.ac.uk/cru/projects/stardex/).

Stuczyinski, T., G. Demidowicz, T. Deputat, T. Górski, S. Krasowicz and J. Kuś (2000), "Adaptation Scenarios of Agriculture in Poland to Future Climate Changes", *Environmental Monitoring and Assessment*, Vol. 61, No. 1, pp. 133–44.

Thuiller, W., S. Lavorel, M.B. Araújo, M.T. Sykes and I.C. Prentice (2005), "Climate change threats to plant diversity in Europe", *Proceedings of the National Academy of Science*, Vol. 102, No. 23, pp. 8245–50.

Vajda, A., A. Venalainen, H. Tuomenvirta and K. Jylha (2004), "An estimate of the influence of climate change on heating energy demand on regions of Hungary, Romania and Finland", *Quarterly Journal of the Hungarian Meteorological Service*, Vol. 108, pp. 123–40.

Venalainen, A., B. Tammelin, H. Tuomenvirta, K. Jylha, J. Koskela, M.A. Turunen, B. Vehvilainen, J. Forsius and P. Jarvinen (2004), "The influence of climate change on energy production and heating energy demand in Finland", *Energy & Environment*, Vol. 15, No. 1, pp. 93–109.

World Health Organization (WHO) (2005), *Health and climate change: The now and how. A policy action guide*, World Health Organization Regional Office for Europe, Copenhagen (http://www.who.it/globalchange/Publications/20051202_1?PrinterFriendly=1&).

Appendix I. Complete list of literature reviewed for the assessment of climate change impacts

Major reports and projects	
IPCC (2007a), "Climate Change 2007: The Physical Science Basis", Working Group I Contribution to the *Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge: Cambridge University Press.	Chapter 11 of the report provides climate projections for Europe and mentions differences among European regions. The information is based on a number of studies, including those from the PRUDENCE project, listed below.
IPCC (2007b), "Climate Change 2007 – Impacts, Adaptation and Vulnerability", Working Group II Contribution to the *Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge: Cambridge University Press.	The contribution of Working Group II provides an assessment of the impacts of future climate change on regions in the world including Europe (Chapter 12). It gives a detailed assessment of the effects of future climate change and a sea-level rise on ecosystems, water resources, agriculture and food security, human health, coastal and low-lying regions, industry and settlements.
Bates, B.C., Z.W. Kundzewicz, S. Wu and J.P. Palutikof (eds) (2008), *Climate Change and Water*, IPCC Technical Paper, IPCC Secretariat, Geneva, June.	Chapter 5 of this recent IPCC technical paper analyses regional aspects of climate change and water resources. It identifies temperature and precipitation changes within Europe that vary across regions. A number of effects of these changes are explored.
European Environment Agency (EEA) (2008), *Impacts of Europe's changing climate – 2008 indicator-based assessment*, EEA Report No. 4/2008, EEA, Copenhagen, October.	This report provides information on past and projected climate change and its effects through about 40 indicators, and highlights that vulnerable regions and sectors vary widely across Europe.
European Commission (2009a), *Impact Assessment*, Commission Staff Working Document accompanying the White Paper on Adapting to Climate Change: Towards a European Framework for Action (COM(2009, 147 final), SEC(2009) 387/2, Brussels. ————— (2009b), *Climate Change and Water, Coasts and Marine Issues*, Commission Staff Working Document accompanying the White Paper on Adapting to Climate Change: Towards a European Framework for Action (COM(2009, 147 final), SEC(2009) 0386 final, Brussels. ————— (2009c), "*Human, Animal and Plant Health Impacts of Climate Change*", Commission Staff Working Document, accompanying document to the White Paper on Adapting to Climate Change: Towards a European Framework for Action (COM(2009, 147 final), SEC(2009) 416, Brussels.	The European Commission's *Impact Assessment* and the other working documents accompanying the very recent White Paper on adaptation include an overview of climate change impacts on regions and countries in Europe. They refer to a number of studies and projects, including the IPCC's *Fourth Assessment Report* of 2007 and the EEA's 2008 report cited above, as well as a number of the projects in this list.

Major reports and projects	
————— (2009d), *Adapting to Climate change: The Challenge for European Agriculture and Rural Areas*, Commission Staff Working Document accompanying the White Paper on Adapting to Climate Change: Towards a European Framework for Action (COM(2009, 147 final), SEC(2009) 417, Brussels.	
European Commission (2008), *Regions 2020: An Assessment of Future Challenges for EU regions*, Commission Staff Working Document SEC(2008) 2868 final, Directorate-General for Regional Policy, Brussels, November. ————— (2009e), *Regions 2020: The Climate Change Challenge for European Regions*, background document to Commission Staff Working Document, *Regions 2020: An Assessment of Future Challenges for EU regions* (SEC(2008) 2868 final), Directorate-General for Regional Policy, Brussels, March.	The recent background document and the Commission Staff Working Document provide a first prospective analysis of the likely regional impacts of climate change in Europe. Mainly the repercussions on temperature and precipitation as well as their effects on socio-economic conditions are outlined. The uncertainties of the findings stem from the projections of climate conditions in the future and the more aggregated data on which some modelling results are based.
Atomic Energy Authority (AEA) (2007), *Adaptation to Climate Change in the Agricultural Sector*, AGRI-2006-G4-05, AEA Energy & Environment and Universidad de Politécnica de Madrid.	This report examines the impact of climate change on different European agri-climatic zones.
PESETA (Projection of Economic Impacts of Climate Change in Sectors of Europe based on Bottom-up Analyses) (http://peseta.jrc.ec.europa.eu/index.html)	The PESETA project has undertaken a multi-sector analysis of the effects and economic costs of climate change in Europe, along with adaptation responses. The analysis is based on bottom-up or sectoral physical assessments, using state-of-the-art methods and knowledge of the physical ramifications of climate change. The results include comparisons of estimates for SRES-based scenarios. The project evaluates the effects of climate change in five different scenarios: one for the 2020s and four for the 2080s.
ADAM (Adaptation and Mitigation Strategies: Supporting European Climate Policy) (http://www.adamproject.eu/)	The ADAM project primarily assesses the policy options for mitigation and adaptation for Europe. Among others, certain project teams examine the risks and vulnerabilities of flooding and droughts for European regions and sectors, as well as the associated costs.
PRUDENCE (Prediction of Regional Scenarios and Uncertainties for Defining European Climate Change Risks and Effects) (http://prudence.dmi.dk/)	The PRUDENCE project seeks to produce dynamically downscaled high-resolution scenarios of climate change for Europe, although with projections only for the period after 2071–90.

Major reports and projects	
ENSEMBLES (http://ensembles-eu.metoffice.com)	This FP6 project has provided better knowledge of the earth's climate system and climate change forecasts at the regional level, including uncertainties. It has developed an ensemble prediction system for climate change based on an array of high-resolution climate and impact models for Europe.
STARDEX (Statistical and Regional Dynamical Downscaling of Extremes for European regions) (http://www.cru.uea.ac.uk/projects/stardex/)	The STARDEX project seeks to provide methods for constructing scenarios of extremes. The more robust techniques are used to produce future scenarios of extremes for European case-study regions for the end of the 21st century. These will help to address the vital question of whether extremes will occur more frequently in the future.
MICE (Modelling the Impact of Climate Extremes) (http://www.cru.uea.ac.uk/cru/projects/mice/index.html)	The MICE project examines the impact of climate extremes, initially aiming at identifying and cataloguing extremes in observed and modelled climate data. Other major objectives include assessing future changes in climate extremes as well as the impact of these changes on specified economic sectors.
CLAVIER (Climate Change and Variability: Impact on Central and Eastern Europe) (http://www.clavier-eu.org/)	The CLAVIER project studies three representative Central and Eastern (CEE) countries in detail: Hungary, Romania and Bulgaria. The project produces in-depth local and regional impact assessments based on climate projections. Climate change simulations and the assessment of uncertainties result in regional climate models that provide optimised input data for climate impact studies. Finally, an evaluation of the economic impact on CEE agriculture, tourism, energy supply and the public sector is conducted.
ALARM (Assessing Large-scale Risks for Biodiversity with Tested Methods) (http://www.alarmproject.net)	The ALARM project provides models and maps of climate change effects for various policy scenarios. Risk assessments in ALARM are hierarchical and examine a range of organisational (genes, species and ecosystems), temporal (seasonal, annual and decadal) and spatial scales (habitat, region and continent).
CECILIA (Central and Eastern Europe Climate Change Impact and Vulnerability Assessment) (http://www.cecilia-eu.org/)	The CECILIA project aims at an in-depth assessment of the climate change impacts and vulnerability in agricultural sectors. It also provides an assessment of water resources, forestry and air quality in targeted areas of Central and Eastern Europe. The research builds on, among other studies, the above-mentioned MICE, STARDEX, PRUDENCE and ENSEMBLES projects.

Major reports and projects	
cCASHh (Climate Change and Adaptation Strategies for Human Health in Europe) (http://www.euro.who.int/ccashh)	This WHO-coordinated research project examines, among others, the impacts of extreme weather events on health and the effects of climate change on water, food and vector-borne diseases. It recognises that in the case of certain diseases, changes in climate will have different implications for different parts of Europe.
ATEAM (Advanced Terrestrial Ecosystem Analysis and Modelling) (http://www.pik-potsdam.de/ateam/)	The ATEAM project focuses on the vulnerability of ecosystem services. Its tasks include developing scenarios for climate change up to the year 2100 as well as maps depicting regions and sectors that are especially vulnerable.
DINAS-COAST (Dynamic and Interactive Assessment of National, Regional and Global Vulnerability of Coastal Zones to Climate Change and Sea-Level Rise) (www.dinas-coast.net/)	This integrated modelling project combines science and data from a range of different disciplines to help policy-makers interpret and evaluate coastal vulnerability to, impacts of and adaptation to climate change.
CIRCE (Climate Change and Impact Research: The Mediterranean Environment) (http://www.circeproject.eu)	The main objectives of the CIRCE project include predicting and quantifying the physical impacts of climate change as well as evaluating the consequences for the society and the economy of the Mediterranean area.
ASTRA (Developing Policies & Adaptation Strategies to Climate Change in the Baltic Sea Region) (http://www.astra-project.org/)	The ASTRA project assesses the effects of climate change on both natural and socio-economic systems, and develops strategies and policies for adaptation. Threats arising from climate change in the region, such as extreme temperatures, droughts, forest fires, storm surges, winter storms and floods, are addressed.
MACIS (Minimisation of and Adaptation to Climate Change Impacts on Biodiversity) (http://www.macis-project.net/summary.html)	One of the MACIS project's two major research questions focuses on a comprehensive assessment of what is already known about the observed and the potential impacts of climate change on biodiversity in Europe.
COCONUT (Understanding effects of land-use changes on ecosystems to halt loss of biodiversity due to habitat destruction, fragmentation and degradation) (http://coconut-project.net/summary.html)	The COCONUT project synthesises existing data about habitat fragmentation and land-use change projections, along with the effects on biodiversity for the EU.
MONARCH (Modelling natural resource responses to climate change) (http://www.eci.ox.ac.uk/research/biodiversity/monarch.php)	The MONARCH project assesses the impacts of projected climate change on wildlife in Britain and Ireland, with a focus on the potential for change in the ranges of species.

Individual articles and reports	
Rodríguez-Fonseca, B., E. Sánchez and A. Arribas (2005), "Winter climate variability changes over Europe and the Mediterranean region under increased greenhouse conditions", *Geophysical Research Letters*, Vol. 32, No. 13.	This study analyses regional changes in seasonal precipitation across Europe in two 30-year simulations using a global and a regional climate model. It also considers the relationship between seasonal precipitation over the European Mediterranean region and the North Atlantic atmospheric patterns in the winter season.
Scherrer, S.C., C. Appenzeller, M.A. Liniger and C. Schär (2005), "European temperature distribution changes in observations and climate change scenarios", *Geophysical Research Letters*, Vol. 32, No. 19.	This study investigates changes in the distribution of seasonal surface temperature in Central Europe, including the use of a set of IPCC SRES A2 and B2 climate-change simulations. For the 21st century, all climate scenario runs suggest large relative increases in the mean for all seasons with the maximum amplitude in summer as well as a tendency for increasing (decreasing) variability in future summers (winters).
Thuiller, W., S. Lavorel, M.B. Araújo, M.T. Sykes and I.C. Prentice (2005), "Climate change threats to plant diversity in Europe", *Proceedings of the National Academy of Science*, Vol. 102, No. 23, pp. 8245–50.	This study projects late 21st century distributions for 1,350 European plant species under seven climate change scenarios. Expected species loss and turnover proved to be highly variable across climate change scenarios and across regions.
Leckebusch, G.C., U. Ulbrich, L. Fröhlich and J.G. Pinto (2007), "Property loss potentials for European mid-altitude storms in a changing climate", *Geophysical Research Letters*, Vol. 34, No. 5.	In this study, loss potential under climate change conditions is shown for the UK and Germany. The inter-annual variability of extreme events increases, leading to a higher risk of extreme storm activity and related losses.
Seneviratne, S.I., D. Lüthi, M. Litschi and C. Schär (2006), "Land-atmosphere coupling and climate change in Europe", *Nature*, Vol. 443, No. 7108, pp. 205–09.	This study examines the expected inter-annual variability of the summer climate in Europe and other mid-latitude regions, potentially causing heat waves to occur more frequently. It performs regional simulations of recent and future climatic conditions with and without land–atmosphere interactions.
Agrawala, S. (ed.) (2007), *Climate Change in the European Alps: Adapting Winter Tourism and Natural Hazards Management*, OECD, Paris.	This report provides an assessment of the impacts of, and adaptation to, climate change in the areas of winter tourism and natural-hazards management for the European Alps.
Hallegatte, S., J-C. Hourcade and P. Ambrosi (2007), "Using Climate Analogues for Assessing Climate Change Economic Impacts in Urban Areas", *Climatic Change*, Vol. 82, Nos. 1-2, pp. 47–60.	This study uses climate scenarios from two models of the PRUDENCE project to develop criteria for monthly mean temperature, total annual precipitation and monthly mean precipitation in order to find present-day cities analogous to 17 future European cities. It then performs an economic assessment of climate change impacts.

Individual articles and reports	
Stuczyinski, T., G. Demidowicz, T. Deputat, T. Górski, S. Krasowicz and J. Kuś (2000), "Adaptation Scenarios of Agriculture in Poland to Future Climate Changes", *Environmental Monitoring and Assessment*, Vol. 61, No. 1, pp. 133–44.	This paper shows that predicted climate change according to GISS and GFDL scenarios will significantly affect farming conditions in Poland through water deficit, shifts in planting and harvesting seasons, changes in crop yields and crop structure.
Patz, J.A., D. Campbell-Lendrum, T. Holloway and J.A. Foley (2005), "Impact of Regional Climate Change on Human Health", *Nature,* Vol. 438, No. 7066, pp. 310–17.	This review estimates changes in human mortality caused by climate change, mainly through causes such as diarrhoea, malaria, floods, malnutrition and cardiovascular diseases. It examines both direct temperature effects and other major risks, such as altered storm patterns, hydrologic extremes and sea-level rise. Three European regions are distinguished.
Rehdanz, K. and D. Maddison (2005), "Climate and Happiness", *Ecological Economics*, Vol. 52, No. 1, pp. 111–25.	This paper estimates the impact of climate change on happiness in terms of self-reported subjective well-being in 25 EU countries.

About CEPS

Founded in Brussels in 1983, the Centre for European Policy Studies (CEPS) is among the most experienced and authoritative think tanks operating in the European Union today. CEPS serves as a leading forum for debate on EU affairs, but its most distinguishing feature lies in its strong in-house research capacity, complemented by an extensive network of partner institutes throughout the world.

Goals

- To carry out state-of-the-art policy research leading to solutions to the challenges facing Europe today.
- To achieve high standards of academic excellence and maintain unqualified independence.
- To provide a forum for discussion among all stakeholders in the European policy process.
- To build collaborative networks of researchers, policy-makers and business representatives across the whole of Europe.
- To disseminate our findings and views through a regular flow of publications and public events.

Assets

- Complete independence to set its own research priorities and freedom from any outside influence.
- Formation of nine different research networks, comprising research institutes from throughout Europe and beyond, to complement and consolidate CEPS research expertise and to greatly extend its outreach.
- An extensive membership base of some 120 Corporate Members and 130 Institutional Members, which provide expertise and practical experience and act as a sounding board for the utility and feasability of CEPS policy proposals.

Programme Structure

CEPS carries out its research via its own in-house research programmes and through collaborative research networks involving the active participation of other highly reputable institutes and specialists.

Research Programmes

Economic & Social Welfare Policies
Energy, Climate Change & Sustainable Development
EU Neighbourhood, Foreign & Security Policy
Financial Markets & Taxation
Justice & Home Affairs
Politics & European Institutions
Regulatory Affairs
Trade, Development & Agricultural Policy

Research Networks/Joint Initiatives

Changing Landscape of Security & Liberty (CHALLENGE)
European Capital Markets Institute (ECMI)
European Climate Platform (ECP)
European Credit Research Institute (ECRI)
European Network of Agricultural & Rural Policy Research Institutes (ENARPRI)
European Network for Better Regulation (ENBR)
European Network of Economic Policy Research Institutes (ENEPRI)
European Policy Institutes Network (EPIN)
European Security Forum (ESF)

CEPS also organises a variety of activities and special events, involving its members and other stakeholders in the European policy debate, national and EU-level policy-makers, academics, corporate executives, NGOs and the media. CEPS' funding is obtained from a variety of sources, including membership fees, project research, foundation grants, conferences fees, publication sales and an annual grant from the European Commission.

E-mail: info@ceps.be
Website: http://www.ceps.be
Bookshop: http://shop.ceps.be

CENTRE FOR EUROPEAN POLICY STUDIES

Place du Congrès 1 • B-1000 Brussels
Tel: 32(0)2.229.39.11 • Fax: 32(0)2.219.41.51