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THE FISCAL IMPLICATIONS OF CLIMATE CHANGE ADAPTATION

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PART II

Literature Review, Case Studies and Fiscal Adaptation Costs

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List of abbreviations

ACIA	Arctic Climate Impact Assessment
AEZ	Agro-Ecological Zone
AGRI	Adaptation to Climate Change in the Agricultural Sector
AWG	Working Group on Ageing Population and Sustainability
a.s.l.	above sea level
BMWi	Bundesministerium für Wirtschaft und Technologie Federal Ministry of Economics and Technology
BMU	Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
CAP	Common Agricultural Policy
cCASHh	Climate Change and Adaptation Strategies for Human Health
CBA	Cost-Benefit-Analysis
CGE	Computable General Equilibrium
CIPRA	Commission Internationale pour la Protection des Alpes International Commission for Alps Protection
CLIMAGRI	Climate Change and Agriculture
CLM	Climate Limited-area Modelling, a regional climate model for Europe
CMED	Central Mediterranean region
DAS	Deutsche Anpassungsstrategie German Strategy of Adaptation
Destatis	Federal Statistical Office
DICE	Dynamic Integrated Model of Climate and the Economy
DIVA	Dynamic and Interactive Vulnerability Assessment
DWD	Deutscher Wetterdienst Germany's National Meteorological Service
EC	European Commission
EEA	European Environment Agency
EnBW	Energie Baden-Württemberg AG
ETS	Emission Trading System
EU	European Union
FAO	Food and Agriculture Organization
FINSKEN	A regional climate model for Finland
GCM	Global Climate Model
GNP	Gross National Product
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GKSS	Gesellschaft für Kernenergieverwertung in Schiffbau und Schifffahrt Helmholtz Research Centre Geesthacht
GTAP	Global Trade Analysis Project
GTAP-EF	A CGE model focussing on economic effects of climate change
IDDRI	Institut du développement durable et des relations internationales
ILO	International Labour Organization

IMAGE	
IMEL	Italian Ministry for the Environment and Territory
IMF	International Monetary Fund
IPCC	Intergovernmental Panel on Climate Change
ISTO	Climate Change Adaptation Research Programme
JRC	Joint Research Centre European Commission
KLIWA	Climate change and consequences for the water management
KLUM	Kleines Land Use Model
KomPass	Competence Centre Impact and Adaptation
MCA	Multi Criteria Analysis
MGME	Multi Global Model Ensemble
NAS	National Adaptation Strategy
NHS	National Health Service
NTO	National Tourist Organisation or Tourist Boards
OECD	Organisation for Economic Co-operation and Development
OIV	International Organisation of Vine and Wine
PESETA	Projection of Economic impacts of climate change in Sectors of the European Union based on bottom-up Analysis
PIK	Potsdam Institute for Climate Impact Research
ppm	parts per million
REMO	Regionales Klimamodell Regional Climate Model
RICE	Regional Integrated model of Climate and Economy
SAL.VE	Safeguarding of Lagoon Venice
SLR	Sea Level Rise
SRES	Special Report on Emissions Scenarios
STAR	Statistisches Regionalisierungsmodell Statistical Regionalisation Model
SWOPISM	Static World Policy Simulation
TSA	Tourism-Satellite-Accounts
UBA	Umweltbundesamt Federal Environment Agency
UKCIP	United Kingdom Climate Impact Programme
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
VSL	Value of Statistical Life
WETTREG	Wetterlagen basierte Regionalisierungsmethode Weather-based Regionalisation Method
WHO	World Health Organization
WIAGEM	World Integrated Assessment General Equilibrium Model
WTP	Willingness To Pay

PART II

1. Introduction and Structure of PART II

PART II presents the background research for PART I - it presents a literature review on the quantification of adaptation costs and fiscal implications, the case studies for Germany, Finland and Italy and a review of knowledge gaps and problems with the present state of the art in general equilibrium modelling. The value added of the case studies and the methodological review is that those indicate the areas in which future research is needed to understand the future fiscal implications of climate change. It also provides a view on how climate change will drive costs and impact state fiscal balances.

The case studies identify both the areas where public action is required for a number of climate impacts, and those areas where only autonomous adaptation will need to take place. This approach provides a basis for determining the areas where intervention is required and the cost implications. Through appropriate cost-benefit analysis it is possible then for public authorities to devise the right type of policies - either regulatory, fiscal or a combination of both - to minimise welfare losses and the fiscal implications.

They also identify impacts where government budgets are affected negatively through the impacts on the economy. Climate change impacts will affect the countries' wealth and thus the tax composition and government revenues. A combination of costs and revenue impacts can hurt the fiscal stability of member states. The review and case studies demonstrate that without careful planning, the fiscal position of countries could be at risk.

The results of the case studies, complemented by top-down cost estimates on adaptation measures in Europe, are listed in an adaptation cost matrix. It sorts the cost estimates available in the literature by region, underlying scenarios, time periods, and impact sectors. The large knowledge gaps become visible at a glance, while giving some measure of fiscal implications for some categories.

As a general result of the case studies and the literature review, a considerable lack of data and quantitative cost analyses becomes apparent. The research of adaptation costs is still in its infancy, so statements concerning the budgetary burdens by adaptation are necessarily still very uncertain. However, the present analysis identifies the sectors with potentially high public costs and in which sectors more research is necessary.

Part II is divided into seven chapters including the introduction. Chapter 2 presents a literature review on climate change impacts and adaptation in Europe. Chapter 3 describes the methodology for the case studies, which are presented in chapters 4 to 6. Chapter 7 presents the knowledge gaps identified and a matrix clarifying the limited knowledge available today.

2. Literature review on climate change impacts and adaptation in Europe

2.1. Literature review

This chapter gives an overview of the available literature on climate change impacts and adaptation in Europe. It identifies knowledge gaps concerning data and methodologies and ends with a note on modelling adaptation costs with Computable General Equilibrium (CGE) models.

The effects of climate change have already become noticeable. This holds true not only for highly vulnerable regions in developing countries but also for Europe. The effects may vary considerably between European regions and sectors. In the recently published White Paper the European Commission has identified the most vulnerable regions (Southern Europe, the Mediterranean Basin, Outermost regions and the Arctic) and sectors (agriculture and forestry, health, water, coasts and marine issues, biodiversity and ecosystems, production systems and infrastructure). This chapter focuses on expected climate change damage and adaptation costs in Europe. The basis is a comprehensive literature review of studies estimating climate change effects in Europe or European regions. The state-of-the-art in this area is presented, and the methodological difficulties and existing knowledge gaps are highlighted.

Although there is a vast amount of information about the direct effects of warming on a host of resources, only few studies have linked these direct effects to damage costs. Furthermore, during the literature review, it has become clear that the literature on damage costs estimates in Europe is not as extensive as for global estimates or the United States. Studies that do derive estimates for Europe usually do that for the regions of *Western Europe*, *Eastern Europe and the former Soviet Union*, or the *European OECD countries,* which is mainly due to available data sets. For further research on estimates for the European Union a new regional focus would be required. There is also a need for more regionalization of the models and harmonization of top-down and bottom-up approaches. Top-down models rely on aggregate damage functions, the simplest of which calculate global damages as a function of only the global-mean temperature change. More recent regional models have constructed damage functions based on regional temperatures. Thus, top-down models generally lack spatial and structural detail. In contrast, bottom-up models have sought to capture the individual direct effects of climate change across the landscape. While these models allow capturing the spatial detail given by climate models, they have not yet developed sound damage estimates because they do not seek to estimate welfare effects and to account for adaptation.

Most of the studies use a top-down approach. Results include estimates for residual damage costs, mitigation costs and (rarely) adaptation costs. Some studies quantify welfare impacts whereas others rather present numbers in terms of market impacts. Further differences concern the applied models and sub-models as well as assumptions on discount rates, emission scenarios and temperature change. On a large scale, results appear consistent. However, due to the differences in models, assumptions and parameters, the aggregation and comparison of studies and the derivation of common conclusions are rather difficult. All the same, it can be assessed that all those studies deriving dynamic results estimate effects to be rather beneficial in the near future, but then to be adverse in the long run. Also, damage estimations for Western Europe are consistently higher in magnitude than those for Eastern Europe and the former Soviet Union. Most of the studies include at least partly adaptation to climate change. The inclusion of adaptation and the underlying assumptions, however, vary largely between studies. For example, while some studies neglect adaptation, other studies assume that the optimal extent of adaptation will be implemented. The results of all studies are summarized in the form of short descriptions where the consideration of adaptation and methodological problems are highlighted. For the identified knowledge gaps and research needs see PART I, chapter 6.

In the following, we summarize the methodological approaches and results of the primary studies in order to present the state-of-art in the field of adaptation.

Kane et al. (1992) estimate the economic effects of a doubling of atmospheric carbon dioxide concentration on world agriculture. The study examines global and regional economic effects. General Circulation Models (GCM´s) and crop response studies are the basis for the analyses of the economic effects of climate change on agriculture. To estimate the welfare effects in the agriculture sector, the study uses a world food model - the Static World Policy Simulation (SWOPSIM). SWOPSIM describes world agricultural markets through a system of domestic supply and demand equations specified by matrices of variables that describe the responsiveness of quantities of agriculture commodities supplied and demanded to changes in commodity prices. The welfare effects in the model are measured by the change in consumer and producer surplus.

The SWOPSIM modelling framework does not include explicit climate variables and so the model doesn't include variables to describe the process of adaptation. Climate changes are introduced exogenously into the SWOPSIM framework. Changes in climatic conditions are introduced as increases or decreases in base yields for specific countries/regions. To estimate the impacts of climate change on the agricultural sector, the study uses GCMs and crop response studies. The study uses two alternative climate change scenarios, i.e. a moderate and an adverse impact scenario.

The impact of climate change on agriculture is estimated to be small with some winners and some losers. In every case the effect in producer surplus is positive. This is due to the reduced domestic yields from climate change which increase international agriculture prices and so the producer surplus. The same effect reduces consumer surplus. So the net welfare effect of climate change on domestic economies depends on a country's net trade position. If a country is a large net exporter the consumer surplus gain will be larger relative to the consumer surplus loss. If a country is a large net importer, the consumer surplus loss will be large relative to the producer surplus gain. For the adverse impact scenario the net welfare effect is estimated to be -0.40% of 1986 GDP for the European Community. For the moderate impact scenario the net welfare effect is estimated to be -0.019% of 1986 GDP for the European Community.

Limitations of the study include: (1) it is a partial-equilibrium model and does not measure interactions with other economic sectors and so neglects spillover and multiplier effects; (2) the framework does not explicitly incorporate resource inputs; rather the model implicitly assumes that uses of resource supplies will be appropriately altered to fulfil new demand and supply conditions following a shock of the base system; (3) the model provides a "snapshot" of the economic impact that a doubling of CO_2 might have on world agriculture, because the model is static in the sense that it does not assume any response by farmers to changing climate conditions, and does not introduce changes in technology, population, or other growth conditions; (4) the analyses has been restricted to the country/regional level, but the climate differs within countries/regions; (5) limitations in climate forecasts make it difficult to translate forecasted expected changes in the climate system into economic impacts.

Fankhauser (1992) estimates climate damage costs caused by a doubling of atmospheric CO_2 concentration across economic sectors and in total. The author estimates damages which $2xCO_2$ would cause to a world with the economic structure of 1988. In the study six regions are considered: EC, USA, former USSR, China, the OECD nations (including EC and USA) and the World as a whole. The study analyses the effect of climate change in different activities and sectors. These activities and sectors are classified in terms of losses of property, biodiversity losses, primary sector damage, human wellbeing and disaster risk. The study estimates the costs of preventing capital loss, dry land loss, coastal wetland loss, species and ecosystems loss, costs in the agriculture and forestry sector, reduction in fish harvests, damage to the water and energy sector, damage to human amenity, damage from increased morbidity and mortality, damage through increased air pollution, migration costs and costs from natural disasters. The study deals with each of the main aspects in separate sections and concentrates on the direct impacts of global warming. The total damage for the European Community is estimated to be 65.6 bn $ or 1.5% of GNP.

Concerning adaptation, Fankhauser assumes that highly developed areas such as cities or tourist beaches will be protected against sea level rise whereas undeveloped or sparsely populated regions will be abandoned. The costs of capital protection, which include building, beach nourishment, island elevation as well as maintenance costs, are estimated to be 140 m$ per year for the EC. The basis for this estimate is the study by Delft Hydraulics which estimates the worldwide protection costs for a 1 m sea level rise within 100 years to be 495.48bn$. Fankhauser adapts this cost estimate to a lower sea level rise presuming a polynomial relationship between protection costs and sea level rise. In addition, the estimates are broken down by regions and translated into an annual expenditure stream assuming a discount rate of 1.5%. The assumption that developed areas will be protected also affects other climate-related costs such as dryland loss, coastal wetland loss, fish harvest, and migration costs. In the case of human amenities, Fankhauser estimates the expected change in defence costs, i.e. the change in money spent on space heating or cooling to be 6,992 m$ for the EC. With regard to changes in morbidity and mortality, the author uses moderate estimates assuming full acclimatisation, which includes biological and behavioural adjustments as well as changes in the physical structure of a city. However, he does not provide any cost estimates of these adaptation measures.

Limitations of the study include: (1) it is a partial equilibrium model and does not measure interactions with other economic sectors; it therefore neglects spillover and multiplier effects, (2) uncertainty in predicting the changes in temperature depending variables; (3) the study concentrates on the impact of a doubling of CO_2; global warming however will not stop there and some models suggest that damage will increase exponentially with concentration; (4) the analyses has been restricted to the country/region level, but climate impacts clearly differ within countries/regions; and (5) adaptation is considered only in some sectors.

Reilly et al. (1994) estimate the economic impact in the agriculture sector caused by a doubling of atmospheric trace gas concentration. The study uses the SWOPSIM (Static World Policy Simulation) model of world food markets to estimate the economic effects of climate change. The model contains 20 agricultural commodities, including eight crop, four meal/livestock, four dairy products, two protein meals and two oil product categories. The base year for the model is 1989. The model is constructed to cover the world and treat 33 regions/countries separately. The potential effects of three different climate scenarios for world agriculture are estimated. The first scenario considers CO_2 fertilization and adaptation, the second considers CO_2 fertilization without adaptation, and the third scenario leaves out CO_2 fertilization, still without adaptation. Thereby, the authors implicitly assume that the supply losses do not involve costly adaptation such as irrigation and substantial changes in input investments but only minor adjustments such as shifts in planting dates or a change in of crops. Furthermore the study uses three kinds of general circulation models (GCM). The principal result of the simulation is that for the three GCM assuming CO_2 fertilisation and adaptation, the net annual economic change for the OECD is estimated at between -6,470 million US$ and +5,822 million US$. Without adaptation, impacts are estimated at between -15,101 million US$ and +2,674 million US$. That is, adaptation reduces losses or increases benefits by 3,148 to 8,631 million US$ in the OECD region. Generally, the net economic effect on a country depends jointly on the country's status as a net exporter or importer and whether the yield change was positive or negative.

Limitations of the study include: (1) the model is a static, partial-equilibrium model and does not capture agricultural interactions with other economic sectors; (2) it does not explicitly capture the costs of adjustments; (3) the analysis has been restricted to the regional level, but climate impacts differ within regions; (4) as always, limitations in climate forecasts make it difficult to translate forecasted expected changes in the climate system into economic impacts.

Nordhaus and Yang (1996) present a Regional Integrated model of Climate and Economy (RICE). By disaggregating into countries, the model is able to analyze different national strategies in climate-change policy: (i) the pure market solution in which there are no controls on greenhouse gas emissions, (ii) the efficient cooperative outcome in which all nations agree to reduce emissions in a globally efficient way, and (iii) the non-cooperative equilibrium in which individual nations undertake policies that are in their self-interest and ignore spillovers on other nations. The RICE model is a regional, dynamic, general-equilibrium model of the economy, which integrates economic activity with the impacts of greenhouse gas emissions and climate change. In the model, the world is divided into a number of regions, each endowed with an initial capital stock, population, and technology. RICE includes region-specific emission equations, a global concentration equation, a global climate change equation, and regional climate-damage relationships to integrate the climate-related sectors with the economic model. Climate change is represented by the realized global surface temperature which uses relations based on existing climate models. The RICE model divides the global economy into 10 different regions: the United States, Japan, China, the European Union, the former Soviet Union, India, Brazil and Indonesia as well as 11 large countries, 38 medium-sized countries and 137 small countries. To estimate the climate change impacts in different regions, the authors assume that the damage function from climate change is identical for each industry across different regions and that the cost functions have the same parameters as those estimated for the United States.

In the uncontrolled emissions scenario, the model projects an increase in global mean temperature of 3.06°C from the mid-nineteenth century to 2100. The cooperative strategy lowers global temperature by 0.22°C in 2100 whereas the non-cooperative strategy reduces warming only by 0.086°C. The differences are small because (i) of the long time lag between changes in emissions and temperature increases, (ii) of the nonlinear relationship between CO_2 concentration and temperature, and (iii) of the high cost of emission control which means that the economically efficient strategy is for only a small reduction in CO_2 emissions. The net benefit for the European Union increases from the market solution to the non-cooperative solution by 7.9 billion US$ and from the market solution to the cooperative solution by 28.5 billion US$. The study incorporates adaptation only implicitly within the climate change damage functions that are identical across regions.

Limitations of the study include: (1) the rather simple modelling of regional climate change damage functions and (2) the absence of explicit modelling of adaptation.

Mendelsohn et al. (2000) incorporate autonomous adaptation via the use of response functions. Except for tourism, which is based on an international comparison, the authors apply the response functions for the United States to the entire world. The response functions to climate change are based on empirical studies that have been designed to include adaptation by firms and people to climate change. Separate response functions are estimated for agriculture, forestry, coastal resources, commercial energy, residential energy, tourism and water. Two alternative response functions are used. The first set of response functions is based on a collection of sectoral studies for the United States. These studies use a variety of empirical approaches to build consistent, comprehensive estimates of damages in each sector. Using the net results from each sector, a reduced-form model is constructed which links climate scenarios and welfare impacts for each sector to temperature and precipitation. The second form of response functions is based on a Ricardian approach that relies on cross-sectional analyses and comparisons to reveal how each sector would respond to climate change. Mendelsohn et al. explore the impacts resulting from a 2°C increase in global-mean temperature in 2060, assuming that CO_2 concentration in the atmosphere has doubled from its preindustrial levels and that sea level will rise by 0.5 meter by 2100. Results indicate that some countries are winners and others are losers. The net benefit for Europe is estimated at 0.4 % of GDP by the reduced-form model and 0.2 % of GDP by the Ricardian model. The striking difference between the two models concerns mainly the losing countries, namely non-OECD, for which the Ricardian model predicts a -0.1 % loss of GDP while the reduced-form model predicts a -0.8 % loss of GDP. This clear difference is largely due to the different predictions about agriculture made by the two impact models, indicating the importance of adaptation modelling.

The study has several limitations including: (1) the response functions were calibrated only for the United States; (2) the non-climate information about each country is not as extensive as it should be; (3) non-market effects are not included; (4) the resolution of the model is coarse relative to the size of small countries; (5) the transient response of the climate system is not considered; (6) the simulated climate changes are only due to increased CO_2 and not to the partially compensating effects of anthropogenic sulphate aerosols; and (7) adaptation costs are not included.

Tol (2002a) applies a meta-analytical approach to estimate and value in monetary terms the potential impacts of climate change on agriculture, forestry, unmanaged ecosystems, sea level rise, human mortality, energy consumption, and water resources. Estimates are derived from globally comprehensive, internally consistent studies using General Circulation Model based scenarios. Impacts are estimated for nine regions: OECD-America, OECD-Europe, OECD-Pacific, Central and Eastern Europe and the former Soviet Union, Middle East, Latin American, South and Southeast Asia, Centrally Planned Asia, and Africa. The study investigates the impact climate change would have on the present situation thereby ignoring future changes for example in land use, economic growth or the balance of labour and capital in a country's production function. This approach has the advantage that the results directly indicate potential pressure points and relative vulnerabilities. The author considers autonomous adaptation provided that the primary studies do as well. For example, in the section on agriculture, it is distinguished whether or not farmers adapt to the changed circumstances. If a primary study does not include adaptation, the original estimates are adjusted. The average difference in outcomes resulting from adaptation for the studies that do consider adaptation is added to the outcomes of the studies that do not. Results indicate that adaptation in this sector leads to a clearly stronger (positive) effect of climate change in the European OECD countries. More precisely, the percentage change of Gross Agricultural Product, for a 2.5°C increase in the global mean temperature, increases from 0.55 to 2.09. In case of sea level rise, the author distinguishes between capital costs of protective construction and the costs of foregone land services. Protection costs of a one metre sea level rise for the European OECD countries are estimated to be 136 billion $ at an optimal protection level of 86%. Regarding the change in consumption of water, heating and cooling energy, Tol estimates the climate change impacts for European OECD countries to be -1.5 billion $ for water, +13.1 billion $ for heating, and -20.2 billion $ for cooling. Impact estimates for other sectors such as health, ecosystems and landscapes in which the physical impact of climate change is largely unknown suffer from some crude and sweeping assumptions and do not consider adaptation.

The aggregate estimates are given for the total annual impact of a 1°C increase in the global mean temperature and a 0.2 metre sea level rise; changes are expected to occur over the first half of the 21st century. Results indicate, on balance, a positive effect on the OECD, China, and the Middle East and a negative effect on other countries. In all cases, uncertainties are substantial, so that not even the sign of the impact can be known with reasonable confidence. This analysis reconfirms that the distributional aspects of climate change are very consequential, and that the uncertainty about the impacts is deep. The author emphasizes that much more research is needed in order to place any confidence in the estimates: (1) the underlying studies need to improve in quality, increase in number, and extend to other impact categories (omitted impacts include amenity, recreation and tourism, extreme weather events, fisheries, construction, transport, and energy supply), (2) the static assessment here has to be made dynamic, including both other climate changes and altered socio-economic circumstances, (3) the underlying studies have to be made consistent, with regard to scenarios and assumptions about adaptation and also with regard to the effects one sector would have on others (e.g., water and agriculture), and (4) the distribution of impacts within regions should be considered.

Tol (2002b) builds on Tol (2002a) and develops a model of climate change impacts that takes account of the dynamics of climate change and vulnerabilities. Monetized estimates of the climate change impact are derived and expressed as functions of climate change and vulnerability. Vulnerability is measured by a series of indicators, such as per capita income, population above the age of 65, and economic structure. Impacts are estimated for nine world regions (OECD-America, OECD-Europe, OECD-Pacific, Central and Eastern Europe and the former Soviet Union, Middle East, Latin American, South and Southeast Asia, Centrally Planned Asia and Africa), for the period 2000-2200, for agriculture, forestry, water resources, energy consumption, sea level rise, ecosystems, and health. Impacts can be negative or positive, depending on time, region, and sector. Negative impacts tend to dominate in the further future and in the poorer regions. The aggregated impact on the European OECD members is positive, although starting and ending in the negative. The impact on Central and Eastern Europe and the former Soviet Union is, on the whole, negative. For comparison, the positive impact on OECD-Europe never exceeds 4% of their GDP whereas the negative impacts on Central and Eastern Europe and the former Soviet Union exceeds 8% of their GDP.

Limitations of the study are: (1) the accompanying static impact assessment is far from perfect, with many missing and numerous questionable assumptions; (2) adding the dynamics implies adding more debatable assumptions; (3) uncertainty, although estimated, is not assessed; (4) parameters are varied one at a time; (5) uncertainties about scenarios for population and economic growth, and about the workings of climate systems are ignored; (6) adaptation and adaptation costs are considered only as far as they are considered in Tol (2002a).

Rehdanz and Maddison (2005) estimate the impact of climate change on happiness. Happiness is measured in self-reported well-being. It is expected that individuals have a preference for particular types of climate due to the effects of climate on heating and cooling requirements, on clothing and nutritional needs and on limits imposed to recreation activities. The study analyses a panel of 67 countries to explain differences in self-reported levels of well-being taken from the World Database of Happiness. This database contains information on the average level of well-being of different countries and years. Results indicate that higher mean temperatures in the coldest months increase happiness, whereas higher mean temperatures in the hottest month decrease happiness. Rainfall also significantly affects happiness. In particular, high latitude countries included in the dataset might benefit from climate change whereas countries already characterized by very high summer temperatures would most likely suffer losses. Furthermore the study uses the regression to calculate the change in GDP per capita necessary to hold happiness at its current level in the face of predicted changes in climate for two different time periods (2010-2039, 2040-2069). The study estimates positive results for Denmark, Estonia, Finland, Great Britain, Ireland, Latvia, Lithuania, Netherlands and Sweden. The results are negative for Austria, Belgium, Bulgaria, Czech Republic, France, Germany, Hungary, Italy, Northern Ireland, Poland, Portugal, Romania, Slovakia, Slovenia and Spain.

Limitations of the study are: (1) the analysis has been restricted to the country level, but climate and climate change differ also within countries; (2) there are other consequences of climate change apart from changes in temperatures and precipitation, e.g. extreme weather events, which are likely to have an effect on people's happiness (3) the study does not look into the time it would take people to adapt to a new climate and the discomfort this may cause.

Patz et al. (2005) describe that many human diseases are linked to climate fluctuations. The study reviews the growing evidence that climate-health relationships pose increasing health risks under future projections of climate change and that the warming trend has already contributed to increased morbidity and mortality in many regions of the world. The authors reviewed empirical studies based of path observations of climate-health relationships, and model simulation of projected health risks and regional vulnerability associated with future climate change. The study focus on health implications of climate variability, past and present climate change impacts on human health, future projections and uncertainties. There are two different health implications from climate variability: non-infectious health effects (heat waves and malnutrition because of endangered food supply) and infectious health effects like malaria and diarrhoea.

The study incorporates three European regions, namely EUR-A (Andorra, Belgium, Croatia, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Israel, Italy, Luxembourg, Malta, Monaco, the Netherlands, Norway, Portugal, San Marino, Slovenia, Spain, Sweden, Switzerland, United Kingdom), EUR-B (Albania, Armenia, Azerbaijan, Bosnia and Herzegovina, Georgia, Kyrgyzstan, Poland, Slovakia, Tajikistan, Macedonia, Turkey, Turkmenistan, Uzbekistan, Yugoslavia) and EUR-C (Belarus, Estonia, Hungary, Kazakhstan, Latvia, Lithuania, Moldova, Russian Federation, Ukraine). Additional total death per million in 2000 (compared to baseline climate of 1961-1990) due to climate change: 70 per EUR-A, 1,040 for EUR-B and 290 for EUR-C.

As a possible response to health threats, Patz et al. present early-warning systems and mention their obvious benefits, but do not estimate the costs of implementing such systems. By presenting this adaptation option, they show that the countries which are most vulnerable to human health impacts of climate change (mainly Africa) are least capable to adapt as well as least responsible for historic greenhouse gas emissions.

Limitations of the study include: (1) there is significant uncertainty in all climate-change diseases models; (2) the study neglects the case that people adapt to the new climate conditions; (3) the absence of accounting for positive climate change impacts on human health (e.g. cardiovascular diseases); (4) the study does not offer any monetary aggregates to measure the climate change impacts, such as losses in productivity due to diseases or mortality; (5) primarily the study examines direct-acting temperature effects; (6) the analysis has been restricted to the country/region level, but climate differs within countries/regions.

Berrittella et al. (2006) estimate the economic implications of climate-change-induced variations in tourism demand. The study uses a GTAP-EF model to estimate tourism impacts of climate change and portray the impact of climate change on tourism by means of two sets of shocks, occurring simultaneously. The first set of shocks translates predicted variations in tourist flows into changes of consumption preferences for domestically produced goods. The second set of shocks reallocates income across the world regions, due to higher or lower tourists' expenditure. Consequently, adaptation is included in this study rather implicitly, by the altered tourist flows after a climatic change. Hence, adaptation costs of these changes in behaviour are not considered, either. To estimate these changes in international tourist flows the study uses an econometrically estimated simulation model of bilateral flows of tourists between 207 countries. The model yields the number of international tourists generated by each country. The number of generated international tourists depends on population, income per capita and climate. The study uses a multi-country world computable general equilibrium (CGE) to assess the systemic, general equilibrium effect of tourism impacts and to simulate the impact of exogenous changes in demand pattern and available income in different countries, due to variations in tourism flows.

The principal results of the study are that climate plays an important role in tourist destination choice. Most tourists want to spend holidays in the sun, but temperature should be pleasant and not too hot. That is why adaptation by producers in the tourism sector is difficult and in some cases impossible. So holiday destinations that are currently too cool would see an increase in their popularity and some current destinations may become too hot due to climate change. Climate change will probably not affect the amount of money on recreation and tourism (about 10% of world GDP is now spent on recreation and tourism) but will affect where the money is spent.

In the study eight countries/regions are considered: USA, EU, Eastern Europe and former Soviet Union, Japan, Rest of Annex 1 (developed) countries, energy exporters, China and India and the rest of the world.

The tourism related private domestic demand for market services is estimated to increase annual GDP in the European Union in 2010 by 0.0005%, in 2030 by 0.008% and decrease the annual GDP in 2050 by 0.08%. Thus, the shocks for the European Union are positive in 2010 and 2030, but negative in 2050. The real income of private households (in 1997 US$) in the

European Union is estimated to increase by 13.05 million US$ in 2010, to increase by 373.26 million US$ in 2030 and to decrease by 9242.3 million US$ in 2050.

Limitations of the study include (1) a finer disaggregation could highlight that climate impacts in Europe will be very different between northern and southern countries; (2) the study only considers direct effects of climate change and ignores the effect of sea level rise; (3) the study overlooks other effects of climate change on ski-tourism; (4) the study neglects adaptation responses of tourist supplier, e.g. the offering of alternative leisure activities (5) limitations in climate forecasts make translating forecasted expected changes in the climate system into economic impacts difficult.

Bosello et al. (2006a) estimate the effects of sea level rise using a global computable general equilibrium model with eight regions. Adaptation is included through coastal protection. The model contains information about potential losses of land and cost estimations of coastal protection. Although in reality there will probably be a mix of protection and land loss, the authors focus on the two extreme cases, protection or no protection. Coastal protection is explicitly modelled as an additional investment, thereby including the effects induced by a different final demand in the wider economy. The authors examine the effect of a uniform sea level rise of 25 cm for 2050. For the scenario without coastal protection, the general equilibrium effects are strongest in economies that rely most on agriculture. We also see that those economies which get hit hardest, suffer disproportionally compared to those economies that suffer little consequences of sea level rise. The reason is that little impacted countries gain in their competitive position, as can be seen from the terms of trade. Without coastal protection the EU will experience a small loss of 0.014 % of GDP due to land and capital loss. The protection scenario assumes that the stock of land resources is fully preserved. However, the structure of final demand changes, because investment increases and household consumption decreases. Regional impacts are determined by the interplay of demand effects and changes in the terms of trade. In many countries the GDP expands due to investments in coastal protection. These investments are financed by the global capital market. In the protection scenario the EU experiences losses of 0.022 % of GDP because it attracts little additional investment and is hit hard by the price increase of fossil fuels. This analysis shows that the economy-wide, indirect effects of climate change are, first, substantial compared to the direct effects and, second, distributed differently across regions indicating that reliance only on direct effects may lead to wrong policy implications.

Limitations of the study include (1) only sea level rise is considered, (2) some effects of sea level rise such as flooding, wetland loss and saltwater intrusion are ignored, (3) the use of a static model limits the analysis to short-term effects, (4) the shocks imposed and the assumptions about available policy options are relatively crude, and (5) changes in carbon dioxide emissions are not fed back into the climate scenario.

Bosello et al. (2006b) estimates the impact of climate change on human health. The impacts of climate change on human health are complex. On the on hand global warming would reduce cold-related health problems, but on the other hand global warming would increase heat-related health problems. The assessed health effects in the study are cardiovascular diseases, respiratory diseases, diarrhoea, malaria, dengue fever and schistosomiasis. The authors do not state whether the reported health impacts are calculated under the consideration of (highly probable) adaptation processes. Changes in the morbidity and mortality are interpreted as changes in labour productivity and demand for health care. The study uses a standard multi-country world computable general equilibrium (CGE) model to assess the systemic, general equilibrium effects, induced by global warming. To estimate the economic effects of climate change the authors assume that health impacts produce economic effects through two main mechanisms: first, there is a variation in working hours and second there is a variation in the expenditure for health services. The study estimates an increasing labour productivity for the European Union, because the decrease in mortality/morbidity related to cold stress more than compensates the increase in heat stress related diseases. The direct effect of a higher labour productivity is to higher GDP and utility. Lower incidence of diseases causes less demand for health care by households and the public sector. The study estimates that the climate-change-induced health impacts increase GDP by 0.07% in the European Union.

Limitations of the study include (1) significant uncertainty in climate change disease models; (2) a finer disaggregation could highlight that climate impacts will be different within countries/regions; (3) the implicit exclusion of adaptation of human organisms and health infrastructure to a warming climate.

Kemfert (2007) estimates the impact of climate change and partly adaptation costs in different economic sectors in Germany. Sectors included are: agriculture and forestry, tourism, health system, energy sector and traffic, construction trade and finance. The study uses the WIAGEM model framework to arrive at dynamic damage costs, due to climate change, in the time period until 2100. The model incorporates trading linkages and dynamic growth effects. Climate damages are analysed by an increasing global surface temperature and sea-levels, due to increasing output of greenhouse gases. Due to the increasing global surface temperature, the agricultural sector will suffer from water shortage and droughts. Water shortage and droughts lead to a deterioration of the conditions necessary for growth and to an increased risk of forest fires. Costs of adaption in the agricultural sector will be for example costs due to the increasing water demand, such as synthetic watering. Costs of the climate change in the agriculture and forestry (climate damages and adaption costs) are estimated to be € 3 billion (at constant prices) between 2000 and 2050. Climate change leads to high costs of adjustment in the tourism sector. The costs of adjustment in the tourism sector are estimated to be € 11 billion between 2000 and 2050. The costs of climate damages in this sector are estimated to be € 19 billion between 2000 and 2050. Human diseases are linked to climate fluctuations and so climate change causes rising costs in the health sector, due to heat-related deaths or the appearance of infectious health effect, such as malaria. The costs in the health sector due to climate change are estimated to be € 61 billion between 2000 and 2050. Furthermore, the study estimates that climate change could cause rising energy costs. Extreme weather conditions decrease energy supply and thus lead to rising energy costs. The economic costs of rising energy prices by 20% are estimated to be € 130 billion between 2000 and 2050. The paper estimates rising costs in the insurance sector caused by climate change. Especially reinsurance costs are rising in the between 2000 and 2050, up to € 100 billion, due to an increasing number of natural disasters. The total costs resulting from climate change for Germany are € 96.4 billion during the period until 2015, € 289.8 billion for 2016-2025, € 406.3 billion for 2026-2050, € 922.2 billion for 2051-2075 and € 1,245.4 billion for 2076-2100.

Limitations of the study include (1) significant uncertainty in climate change disease models; (2) prohibited damages due to adaptation measures in some sectors are neglected; (3) a lack of transparent reasoning of the presented estimates, in particular of adaptation costs; (4) a finer disaggregation could highlight that climate impacts will be different within Germany; (5) limitations in climate forecasts make translating forecasted expected changes in the climate system into economic impacts difficult.

Sgobbi and Carraro (2008) estimate the economic value of the impacts of climate change for different Italian sectors and regions. To estimate the variations in GDP due to climate change the study aggregates the sectoral and regional impacts. The study includes autonomous adaptation induced by changes in relative prices and in stock of natural and economic resources. The authors estimate the economic impact of climate change in four sectors: alpine areas, the Italian hydro-geological system, coastal zones and marine environment, areas at risk of desertification.

For the alpine areas, the study estimates that the increasing temperature due to climate change will lead to less snow and snow reliability, thus will negatively impact the winter tourism industry. Also an increase in extreme weather events will decrease the attractiveness of alpine resorts and increase the costs of maintaining and protecting infrastructures. Summer tourism may benefit from higher temperatures. The study estimates that the expected average reduction in income from winter tourism will be 10.2% in 2030 and 10.9% in 2090 for Italy. To mitigate the impacts of climate change in winter tourism, the study identifies several adaptation strategies, however without giving concrete cost-benefit estimates for Italy.

Several strategies are also being used to protect coastal zones from sea level rise, and riverine areas from inundation, increased erosion and other climate impacts. For the most, these strategies are technical measures such as dykes and levees, but there are also behavioural strategies such as changing location of recreational activities, managerial interventions such as changing agricultural practices and political decisions such as land use planning. As for the costs of measures protecting from landslides and riverine floods, Sgobbi and Carraro present the current expenditures in Italy, which are however not taking into account climate change. To illustrate the magnitude of adaptation costs and benefits, data from other European countries are mentioned. For the costs of protection against sea-level rise, there are more data available. The authors conclude that protection costs in Italy are low relative to GDP, but high relative to the prevented land loss.

Climate change is expected to worsen the desertification trend already observed in Italy. Desertification has direct economic effects such as loss of soil and indirect economic effects such as a decrease in agricultural production and an increase of unemployment. The study estimates as a first approximation that the costs of desertification in Italy are about 60-412 million US$/year. There a currently no estimates of the costs and benefits of adapting to increased risks of desertification due to climate change.

The same holds for adaptation responses to heat waves, namely early-warning systems. The benefits of this kind of adaptation are quite well analysed. The authors give an estimate of the cost of one additional death casualty, and the effectiveness of early-warning systems (in terms of number of casualties prevented) is examined in other studies. However, there is no estimate available for the cost of early-warning systems.

Limitations of the study include (1) the study does not estimates the costs of adaptation for all regions/sectors; (2) limitations in climate forecasts make translating forecasted expected changes in the climate system into economic impacts difficult.

De Bruin et al. (2009) develop and apply a framework to include adaptation explicitly as a policy variable in the integrated assessment models AD-DICE and AD-RICE allowing for analyzing the interactions between mitigation and adaptation. Adaptation is included via adaptation cost curves. These cost curves are estimated for the world as well as for different regions. They reflect how different adaptation levels will provide a wedge between gross damages (i.e. damages that would occur in the absence of adaptation) and residual damages (i.e. the damages that would occur with adaptation). Results indicate that both mitigation and adaptation are important in responding to climate change. Both policy control options can compensate to some extent for deviations from the efficient outcome caused by non-optimality of the other control option. The study explicitly examines the global utility losses from various possible inefficient adaptation paths. In particular, the utility loss of a limitation on the adaptation funds is analysed. This is a case which is quite relevant for the real world. But also other restrictions and inefficiencies of adaptation are evaluated, e.g. overinvestment, no early adaptation, or slow adaptation. Overinvestment in adaptation may be worse from a welfare perspective than underinvestment, although moderate overinvestment is still far preferable to no adaptation at all. The report suggests furthermore that optimal adaptation efforts start at a reasonably high level immediately, whereas optimal mitigation levels are slowly increasing over time. At the regional level there are substantial differences in the optimal adaptation efforts. Especially in vulnerable regions, adaptation is an essential ingredient in the policy mix. The AD-RICE model gives quantitative estimates of the gross costs of climate change (in the non-adapted case), the residual damage after adaptation, and the adaptation costs, all in net present value in trillion USD. As for Europe, these figures are 385, 277, and 25 trillion USD. Note that these figures are formulated as the net present value of a future stream of annual costs. Unfortunately, the authors do not state how many future years they include into their calculation, so a translation into annual costs is not possible without further information. They explicitly mention that the results should be treated with caution since they base on "relatively old estimates of damages in the RICE99 model" (page 37). There are also results available for a higher damage scenario; here the costs are 996 tr. USD for gross damage, 647 tr. USD for residual damage, and 82 tr. USD as adaptation costs, again all calculated as the net present value of a payment stream in the future.

There are four major methodological limitations of the study: (1) detailed regional knowledge on damages and adaptation options to reduce these damages are absent, (2) uncertainty and risk aspects are excluded, and (3) the formulation of adaptation in the model is a flow approach, i.e. adaptation is essentially seen as reactive and not anticipative.

2.2. A note of adaptation in CGE models

The literature review has shown that the estimation of climate change damage costs is not an easy task. In particular many knowledge gaps still exist for the estimation of adaptation costs. One possibility to estimate these costs is the application of CGE models. Computable General Equilibrium is nowadays highly regarded as the appropriate tools to assess the costs of implementing various alternative economic policies. Contrary to aforementioned partial economic models, they consider more than one market which allows them also to include the indirect effects from other markets of any policy measure. The discussion around the implementation of General Circulation Models to economic policy analysis focuses mainly on the determination of 'outlays' in particular parts of the economy caused by changes in the climate. They mainly forget that the alternative of no climate change also has its outlays for these sectors. It is the difference in outlays between the alternatives that counts; hence the discussion should concentrate on the opportunity costs of each policy alternative. Opportunity costs are a much broader concept than outlays only and they are the appropriate tools for an economist to make a decision on which policy alternative to take.

A damage function approach, for example in Tol (2002a), only gives an estimate of the particular damage costs inflicted on the economy by changes in climate variables, mostly measured as a percentage of GDP. They do not provide any information on how these costs are changing following the implementation of the policy alternatives. To do so, they should be included into an appropriate and more elaborate economic model. Only, the latter model, in combination with a climate model can give the changes in the climate variables associated with each policy alternative. This damage function approach is hence incapable of a proper assessment of the opportunity costs of alternative policies.

Partial economic models could be taken as the appropriate model to include a damage function, but they only grasp the direct effects on the one market that they are considering. In order to calculate the total costs of implementing a policy in the economy, more markets and their interactions should be taken into account. In that way, also the indirect effects can be included. Computable General Equilibrium models, possibly in an integrated assessment framework with climate models and damage functions, stand out here as the primary policy assessment tool. These models have the advantage that they do consider not only direct effects but also indirect effects of adaptation. In the following we provide a short description of how adaptation costs can in principle included in CGE modelling.

For this purpose, we consider the adaptation of the economy to climate change as a reallocation of the economy’s land according to a climate-induced change in its profitability in the possible production opportunities. Changes in the regional or local climate can have severe implications for the productivity of land. The fact that this land is used in a particular sector has been an economic decision by the owner of the land based on the profitability of this land in the sector, in comparison to possible other alternatives. Climate change causes the owner to change his assessment of the profitability of land in the agricultural sector and might induce him to supply his land to other production opportunities which have become more profitable under the new climate conditions. In order to be able to provide a proper assessment of the impact of adaptation policies in the economy, we should have a model that includes a theory on how such decisions with respect to land-use are made. We assume that the economic decisions concerning optimal production for land is described by the Ricardian land-use theory (Ricardo, 1951-1973).

The climate-induced changes on the profitability of land in each production sector can be included into a CGE model, by reinterpreting the model in the light of Ricardian land-use theory. This approach has not been chosen yet. Instead, a link is made between a CGE model and a particular land-use model. An example of such a linking is the linking between a GTAP computable general equilibrium model and the KLUM (= ‘Kleines Land Use Model’) model in Ronneberger et al. (2006). In such approaches, the allocation of land is treated as exogenously given by the CGE model. Hence, we cannot derive the costs of land-use changes following the implementation of adaptation policies from such a coupled model since the essential decisions are hidden from the CGE model. The KLUM model applies an alternative theory of land use than the one given by Ricardian land use theory and can be seen as conceptually different from the CGE. The KLUM model can however still be seen as an economic land use model. Alternatively, integrated assessment models often resort to land use models such as the IMAGE model (RIVM 2001). Such models only refer to climate induced changes in vegetation and have no basis in economic decisions.

An essential part of including climate change impacts in the CGE model is the choice of damage function (see Tol (2002a, 2002b)). A damage function relates changes in certain climate variables, such as mean global temperature, precipitation, to economic costs in the economy. These economic costs are often taken as a percentage of GDP. Damage functions are an artificial construct meant to summarize for example the results from an underlying, far more elaborate climate model. We fail the knowledge on the appropriate functional form to choose. The functional form is often chosen to facilitate computations or estimation. Underlying data for a sound estimation often fails and one often resorts to a meta-analysis of the few existing studies.

The GTAPE-LTD CGE model extends the GTAP-E model (see Burniaux and Truong (2004)) to the inclusion of land-use effects. The extension of this model is parallel to similar developments in the GTAP project; see Lee et al. (2006), to extend their database and models to land-use. For the modelling of land-use in CGE models we refer to the overview in van der Werf and Peterson (2007). The use of land in a CGE model such as the GTAP models is seen as a good like any other. There is no spatial context to it, nor is there a particular land-use theory underlying the use of land in production. The land used in a production sector is assumed specific to this sector and cannot be applied in any other sectors. During the last years, the GTAP project has been discussing and implementing an extension of their database and models to a more detailed description of land use following the intensified international debate on adaptation measures to climate change. We refer to Lee et al. (2005). The extension of the GTAP-E model is part of this debate.

Lee et al. (2006) give each region in GTAP a land-use matrix. GTAP then distinguishes land according to its allocation to an ‘Agro-Ecological Zone’. Agro-Ecological Zones (see FAO (2000)) segment the land in small parts that depend on its ‘agro-ecological’ characteristics, such as humidity, temperature, land-type, etc... On the other hand, GTAP distinguishes land according to its use in a production sector. Hence, a crop not only uses land as a total, but also land allocated to distinct AEZs. We assume that, at each moment, under a given climate regime, the global allocation of land to the different AEZs is fixed. It is hence important to notice that climate change changes the row totals of the Land Use matrix. Furthermore, notice that GTAP applies so-called ‘harvested area’ data. This means that land that is used for more than one sort of vegetation during a year is counted more than once.

GTAPE-LTD distinguishes production sectors that show a significant distinction in their use of the production factors labour, capital, and AEZs - hence sectors with a very distinct production structure with respect to these inputs - from sectors with a comparable relationship. Only in the case of a similar production structure, we can aggregate the AEZs into an aggregate production factor ‘land’. In the case of distinct production structures, we should consider a ‘Crop’ that uses AEZ1 as an input factor, as a different production sector as a ‘Crop’ that uses AEZ2.

The IPCC defines adaptation to climate change as the “[a]djustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities” Up to now, the project adhered to this definition of adaptation. This section though takes a slightly different view. In an economic context, we refer to a welfare-based approach.

The GTAPE-LTD model has been developed during the international debate on the use of agricultural land for the production of biomass. The GTAP project is very active in this discussion. We refer to Britz et al (2009), and to Hertel et al. (2010). Many western economies are focussing their energy policy to support the use of biomass energy in the energy system. This entailed big subsidies for the production of the appropriate agricultural goods. These subsidies significantly influence the profitability of using land for biomass good production in relation to other goods. One of the consequences of such subsidies was the change of land from the production and supply of food towards biomass. A lack of certain food products was becoming a serious threat. Also, lots of forest land was switching to the production of biomass goods in Brazil. Such deforestation has major influence on land-based greenhouse gas emissions as well as for the global circulation in the Earth's atmosphere. The GTAPE-LTD model can compute the costs of such land-use changes and associated subsidy systems which have to be added to the cost of climate change only. Furthermore, it should calculate the extra greenhouse gas emissions associated with deforestation.

Recently, the International Food Policy Institute (IFPRI) published a study that analyses the impact of possible changes in EU bio fuels trade policies on global agricultural production and its environmental performance (Al-Riffai et al. 2010). In particular, it pays attention to possible indirect land use changes (iLUC), i.e. the changes of land from food production to bio fuel production as mentioned in the previous paragraph, associated with these policies. With the latter, this study is in line with a current debate on whether, and how, iLUC effects should be accounted for in such studies, along with direct land use changes. Indirect land use changes refer to the change of land from deforestation or the conversion of grazing land to crop cultivation following an increase in bio fuels demand. The debate is on whether these iLUC effects can be measured and quantified. Al-Riffai et al. (2010) use a computable general equilibrium model, MIRAGE, calibrated on the GTAP7 database, which is similar to the approach taken by GTAPE-LTD. The computable general equilibrium model is extended with a land use model based on a partitioning of the world in Agro-Ecological Zones. Using a computable general equilibrium modelling approach, they compute average and marginal iLUC for each feedstock.

Al-Riffai et al. (2010) conclude that iLUC effects have an important effect on the sustainability of bio fuels. The study shows the significance of the inclusion of land use changes into the model used for the impact assessment of bio fuels. It also mentions the current limits of data availability that cause significant uncertainty regarding the policy simulations in the study.

The adaptation to climate change follows through changes in land use in the economy. It causes changes in the availability of land for economic purposes and as such it will be of influence on the value of the average and marginal iLUC computed for example by Al-Riffai et al. (2010).

3. Country Case Studies as a bottom-up approach

3.1. Estimating adaptation costs – a bottom up approach

With climate change, public authorities have to contend with a large level of uncertainty and many different implications. Ecosystem variations can affect a large number of economic activities and the functioning of a large number of infrastructures (i.e. water supply systems, etc.). Modelling of climate impacts and any precision on specific areas of the economy is rather weak. As illustrated in the literature review (chapter 2.1), in the case studies (chapters 4, 5 and 6) and in the adaptation cost matrix (chapter 7), the knowledge gaps in general equilibrium modelling of economic effects and adaptation costs of climate impacts shows large unexplored areas. The PESETA project of the JRC is a first attempt to estimate for the whole EU at regional level the economic implications, but results at lower regional level have not yet been published. Results are given as an aggregate of large European regions. PESETA results do not give a full picture of costs as they look at specific climate impacts, nor do they give any indications of fiscal costs, but they pinpoint the areas of highest economic risk and adaptation costs with the potential magnitudes of impacts, trying to present an estimate of welfare effects with and without adaptation efforts. Similarly, and as it is stressed later in this document on information provision, the UK's UKCIP (UK Climate Impact Programme) offers information to local authorities and individuals on climate impacts in their area based on available research .

To decide on actions to limit the costs of adaptation it is important to first study the potential impacts of climate change on territories, identifying the physical effects. From this information, impacts on economic sectors and the welfare of the citizens have to be derived. The subsequent chapters this document presents examples of three case studies on adaptation needs in Germany, Italy and Finland.

The importance and magnitude of action needs to be identified. The regional studies could identify the kind of actions which could be undertaken to reduce the negative impact. Once the parameters are clear, the question will arise on how to induce a behavioural change to avoid the worst impacts. Through a CBA, the state in coordination with regional authorities has to investigate the potential benefits of different actions to counteract the negative impacts, taking into account to what extent planned adaptation is necessary and the direct and opportunity cost of those actions. It is possible that a pure CBA will not suffice and multi-criteria analysis (MCA) is required, i.e. when costing of certain benefits is not possible, such as for impacts on biodiversity or cultural sites.

The first step to develop an adaptation plan at any territorial level is to study the potential impacts of climate change under various scenarios and understanding the probabilities of such events. While uncertainties prevail, a list of impacts at regional level needs to be prepared at appropriate territorial level. It is highly recommended to start from the expected climatic impacts, those are:

- Changes in average temperature in the seasons and expected increase in temperature extremes
- Changes in precipitation patters
- Changes in snow cover
- Changes in water systems: river flow changes (flood and draught risks); groundwater level changes
- Coastal region impacts: sea level rise and flood risks

Based on an assessment of the level of risk of the average changes and the expected frequency and strength of extreme conditions, an analysis has to be undertaken on critical fields affecting the territorial area analysed. Those fields are for example the ones used in the case studies:

- Changes in inland water balance and sea water
- Agriculture and forestry
- Tourism
- Human health
- The energy sector
- The transport sector

3.2. Introductory remarks to the Case Studies

The subsequent case studies explore climate change-induced impacts, sector- and nation-specific vulnerabilities and adaptation measures observed and evaluated in three different member states of the EU, namely Germany, Finland and Italy.

Adaptation to climate change has become an important challenge for private as well as public decision makers, since living conditions will change in an altering climatic environment and adaptation to these changes cannot be left to autonomous action alone. Therefore a number of EU member states have already adopted National Adaptation Strategies; these are Denmark, Finland, Germany, France, Hungary, the Netherlands, Spain, Sweden, and the United Kingdom.

In the strategies and in the present case studies the focus is mainly on critical sectors and fields, which are considered particularly exposed and vulnerable to climate change developments. Thus, besides the fields of water resources, water supply and health, economic sectors such as agriculture and forestry, energy, transportation and tourism sectors are examined. In doing so, adaptation measures – those realised as well as potential ones – are indicated for each sector and country.

The selection of countries for the case studies has been made considering the location and vulnerability of a country. These two aspects are strongly linked as climate change impacts differ according to the geographical location of the country affected.

Firstly, regarding the location, the European Union can be separated into several regions. The common division is based on directions: North, East, South, West and Central Europe. Further breakdowns, as used in the ADAM study, into Baltic States and Central East or North as well as Nordic countries are possible. A case study-based analysis cannot sufficiently cover all of these regions by picking one country of each. Therefore, another form of differentiation needs to be found. Climate change prediction refers to climate zones and so this shall serve as an approach for selecting countries. Climate zones are defined in North-South and not in East-West dimensions; therefore a North-South selection of countries is practical.

According to Trol and Paffen (cited in Diercke Weltatlas 2008, p. 228) the world climate can be divided into five zones: (I) polar and sub polar zone, (II) cold moderate zone/boreal zone, (III) cool moderate zone, (IV) warm moderate zone/sub tropical zone, (V) tropical zone. The countries of the European Union lie in zones I-IV, but there are only small areas within the polar or sub polar area. Therefore, it is justifiable to pick countries of the three remaining zones described. Finland is located in the boreal zone (II) with continental climate. Germany belongs to the cool moderate zone (III) with sub oceanic climate and maritime influences. Italy is part of the warm moderate, subtropical zone (IV) with Mediterranean climate. By selecting these countries all relevant different climate zones within Europe are covered.

Secondly, the selection of countries is made based on considerations of vulnerability. In PART I (Section 2.1) the link between adaptive capacity and vulnerability is explained. The socio-economic and the institutional capacities, as well as the ecosystem's responsiveness are mentioned as determinants of adaptive capacity. This combined with natural effects of climate change then determines the vulnerability of a country. In PART I (Section 3.1) the different physical outcomes of temperature increase and therefore the vulnerability of countries due to their location have already been mentioned. The distinction of Northern and Southern European countries is pointed out in this part. In order to consider this in the case studies, the range should cover North, Middle and South European countries. The selection of Finland, Germany and Italy takes the circumstance of climate change as a multi-faceted phenomenon in Europe into account.

Beside the location and the link to vulnerability as selection criteria, the availability of data in English or German language is also an aspect for choosing countries for the case studies.

In each case study we follow a similar approach. First, an overview of the existing work on National Adaptation Strategies is given. In the following sections the physical and climatic conditions of each country are outlined by presenting multiple study results in respect of past climate trends and climate projections in the future. Based on this analysis, sector- and nation-specific impacts, vulnerabilities and adaptation strategies are presented. It must be stated that this report focuses on direct climate change impacts, which are results of changing environmental conditions. In contrast, we abandon effects of climate policy since this would be a different research topic. Partly, this limitation is considerable, e.g. in the energy sector where the energy mix is only a minor topic (due to growing conditions for biomass or cooling conditions of heat power plants). Concerning adaptation, we differentiate between planned and autonomous adaptation, as well as between anticipatory (proactive) and reactive adaptation.

Due to availability of studies and data (in German or English language), some countries, sectors or regions may be more represented in this study than others.[1]

We will also take into consideration the White Paper on climate change adaptation recently published by the European Commission as well as the accompanying Impact Assessment Report and sectoral studies.

For instance, the study on the agricultural sector provides an assessment of the expected climate induced impacts and risks on farming activities and the correspondent risks, along with a description of potential adaptation options and an evaluation whether and how the Common Agricultural Policy of the EU may work towards adaptation. It also distinguishes between nine agro-climatic zones and examines risks and opportunities in these zones.

The document on adaptation in water, coasts and marine issues also gives an overview of possible impacts on this sector and focuses on adaptation measures of facilitation which could be integrated in existing EU legislation. It highlights relevant EU directives and recommendations, inter alia the “Marine Strategy Framework Directive”, which establishes European Marine Regions and sub regions on the basis of geographical and environmental criteria and commits the member states to develop strategies for their marine waters. These region-specific strategies shall be complemented by climate change adaptation issues, so they might be of interest for the present case studies. However, as these strategies are only due by 2012, they cannot be included in this report.

Finally, the EU sector study on adaptation in the health sector points out a number of health-related impacts of climate change. The authors do not only focus on human health, but also on animal and plant health; they thereby pick up issues which are in this study sorted to the agriculture and forestry sector respectively. In addition to the human health problems

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[1] This is not because of any preference with regard to contents, but due to the fact that data for some aspects or regions date are rarely found in English or German, e.g. the literature for the case of Italy for instance is for the most part in Italian.

mentioned in this study, it contains quantitative estimates of mortality due to temperature rise, food-borne diseases and other health-related issues. As adaptation measures, the EU sector study presents a range of central health programmes (e.g. research and statistic programmes) and their specific tasks. Keywords in the plan of recommended action are surveillance (of diseases) and networking (of existing institutions).

4. Case study I: Climate change impacts and adaptation in Germany

4.1. National Adaptation Strategy and outline of the case study Germany

In Germany, the Federal Ministry of Environment, Nature Conservation and Nuclear Safety is in charge of the official German Strategy of Adaptation (DAS), while the other German Federal Ministries as well as the Federal States back the process substantially. The self-imposed goal is to identify regional impacts at an early stage and to reduce or even prevent damages by taking adaptation measures. The National Climate Protection Programme of the German federal government (BMU 2005) laid the groundwork for the German Adaptation Strategy. Another important step was the implementation of the "Competence Centre Impact and Adaptation" (KomPass) at the Federal Environmental Agency at the end of 2006. The objective of this centre is to sharpen the perception of vulnerability of both public and business decision-makers (UBA 2006). The conceptual phase was kicked-off by an expert conference in April 2008. The German Adaptation Strategy was adopted in December 2008. This study illustrates the efforts of Germany's public authorities and citizens concerning current adaptation to climate change as well as probable measures in the future.

The focus is placed on the period until 2050. A description of climate change until 2100 is, however, also given in order to emphasise a clearer trend of the expected exposure.

Section 4.2 shortly explains the division of Germany into 16 federal states and the classification of 12 environmental zones. As a part of relevance for all the three case studies, section 3.3 presents basic methods of climate modelling and highlights the uncertainties that arise with regional impact assessments. Section 4.4 presents the current, past and future climate in Germany and section 4.5 describes impacts, vulnerability and adaptation measures in critical fields.

4.2. German regional overview

Figure 1 shows the 16 federal states and the 12 environmental zones of Germany. The environmental zones are namely (1) the coastline, the Northern German lowland (split into (2) North-West German lowland and (3) North-East German lowland), (4) the West German lowland bay, (5) the low mountain ranges left and right of the Rhine, (6) the Central low mountain ranges and the Harz, (7) the South-Eastern basin and hills, (8) the Upper Rhine rift, (9) the Alp and Southern German Escarpment Landscape, (10) the Ore Mountains (Erzgebirge), the Thuringian and Bavarian Forests, (11) the Alpine foothills and (12) the Alps. The approach is selected to point out the regional distribution of exposed and particularly vulnerable regions in Germany and to structure possible adaptation measures according to a classification of regions that are affected in different ways.

Figure 1: Federal states and environmental zones in Germany. The federal states (left) and the environmental zones (right). Source: www.anpassung.net

The federal states

The environmental zones

4.3. Climate scenarios, models and uncertainty

Firstly the basic methodology of regional climate modelling is presented to ensure a more differentiated assessment of statements on future climate development in Germany.

One starting point for climate projections are the IPCC emissions scenarios. In these scenarios, consistent basic assumptions with respect to the future development of population, technology, policy and behaviour are made. There are four main socio-economic scenario families, namely

- the assumption of rapid economic growth and convergence among regions (A1),
- a world with persistent heterogeneity among regions (A2),
- a convergent world with rapid development towards service and information economies (B1), and
- a world focussing on local sustainability (B2).

The IPCC regards these “storylines” as equally plausible reference scenarios without any estimation as to their respective probability of occurrence. In many studies, however, emissions projections from the scenario families A2 and B1 are used as extreme values, whereas scenario A1B is quoted as a relatively moderate scenario.

Based on the IPCC emissions scenarios, Global Climate Models (GCM) project worldwide climate development. The IPCC uses 23 different Global Climate Models for its fourth assessment report. These models are often highly concordant, for example concerning global estimates of changes in air temperature. With respect to other climate parameters, such as regional precipitation, models differ considerably.

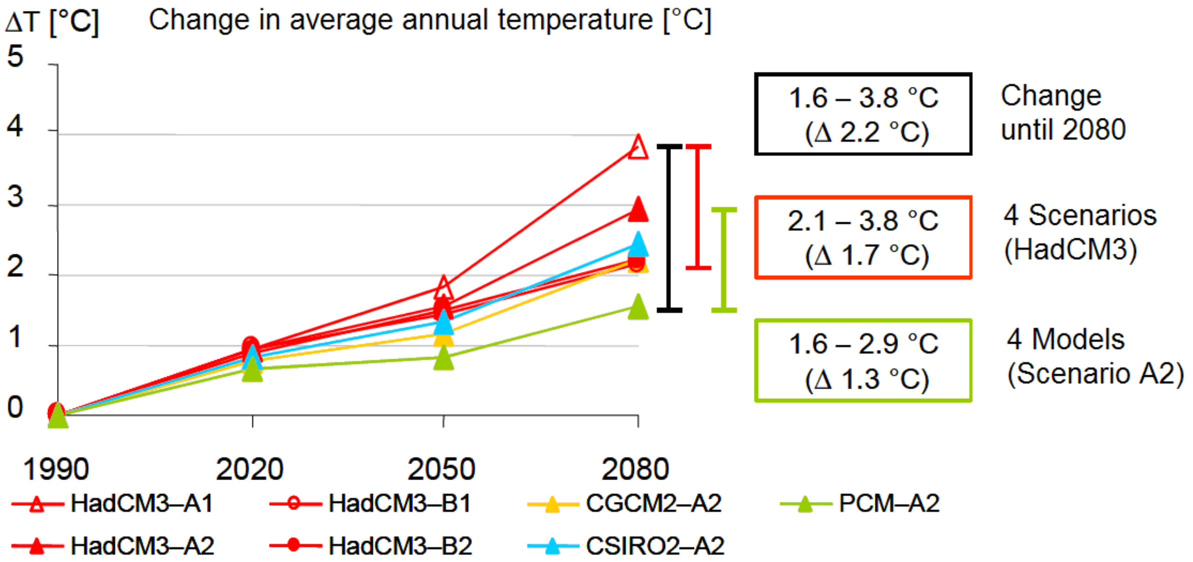
As a next step, Global Climate Models are regionalised in order to take a more differentiated look at climate development in Germany. This is necessary for Central Europe, in particular, since it is often placed in a transition zone in Global Climate Models, i.e. the consequences of a changing climate differ considerably among regions. For Germany, four regionalisation models are currently used for this "downscaling": REMO, CLM, WETTREG and STAR. The former are dynamic models based on physical correlations, which explicitly calculate central climate parameters such as air pressure, precipitation, air currents, radiation etc. on the basis of Global Climate Models. WETTREG and STAR, on the other hand, are statistical regionalisation models which project known weather phenomena from the past to the future using statistical methods. Thus the trend expected in the global models is confirmed for Germany. A drawback of dynamic models is the long computing time, which makes it very difficult to run calculations until 2100 repeatedly. Statistical models have the advantage of calculating as much as 1,000 realisations for climate development until 2100 in reasonable computing time, whereby stochastic deviations are largely evened out. Their disadvantage is, however, that they cannot reliably indicate the intensity of weather events in times of climate change.

- Thus, a number of uncertainty factors may be identified for regional climate projection:
- First, the choice of the underlying IPCC scenario plays an important role.
- The choice of the Global Climate Model is also relevant, as well as possible modelling errors – in particular with respect to estimates for the coming decades.
- The regionalisation of global climate projections entails additional uncertainties in models.
- Finally, every climate projection is subject to uncertainty due to natural variations ("internal climate variability") which cannot be represented in models.

In the following, all these uncertainty factors in connection with estimates on future climate development have to be taken into account. Predictions about precipitation, in particular, are subject to high uncertainty due to modelling errors, while estimations about the temperature at the end of the century rather depend on the choice of the emission scenario.

Figure 2 gives an illustration of the possible scope that has to be considered when estimating the – relatively certain – variable of average annual temperature in Germany, without regionalisation and without consideration of internal natural variability.

Figure 2: Change in average annual temperature in Germany and variability in °C according to four different Global Climate Models and four IPCC scenarios. Source: UBA 2005.



To predict climate change in Germany, the Federal Environment Agency (UBA) uses mainly two approaches for regionalisation. Both regional models, WETTREG (statistical, UBA 2007) and REMO (dynamic, UBA 2008), represent climatic conditions in Germany mostly until 2100. They are based on the socio-economic scenarios presented by the IPCC for the future, primarily scenario families A2, A1B and B1. The German Strategy of Adaptation additionally refers to the projection results of the regional models CLM (dynamic) and STAR (statistical).

This section focuses on calculations based on the IPCC scenario A1B – however, relevant deviations that are possible when assuming other scenarios are also included in the analysis.

4.4. Current, past and future climate in Germany

4.4.1. Current climate and climate change in the retrospective

Current climate

Roughly speaking, a maritime as well as a continental macroclimate may be observed in different parts of Germany. The maritime macroclimate (cool and rainy summers and mild winters) is more relevant to the North and the West, whereas a more continental type of macroclimate (warm and dry summers and cool winters with more variation between summer and winter) plays an important role in the South and East of the country. The average annual temperature in Germany reaches 8.2°C and average annual precipitation reaches approximately 780 mm[2]. Parts of Baden-Württemberg reach maxima of 980 mm and Bavaria and Saarland approximately 940 mm. The continental impact is particularly evident in Eastern Germany, mainly the South-Eastern basin and hills. At approximately 550 mm Brandenburg and Saxony-Anhalt, in particular, receive less precipitation. In contrast, Saxony has higher

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[2] One mm equates to one liter per square meter in a year.

precipitation levels in the low mountain ranges. The northern part of the Upper Rhine rift has low precipitation levels at 550 mm. Temperatures as well as precipitation are dependent on the orographical[3] structure of the land: Precipitation levels are higher at the luff side of the low mountain ranges and the Alps (Zahn et al 1996).

Climate change in the retrospective

The annual temperature increase of +0.9°C during the last century in Germany lies above the global increase of +0.7°C (1901-2007). The largest deviations from this trend showed Saarland with +1.3°C and Mecklenburg-Vorpommern with only +0.5°C (DWD 2008). In the Alps, the temperature increase was three times higher than the global average (Abegg et al. 2007). The duration of snow cover in Baden-Württemberg decreased by 40% and more in lower altitudes, by 20-30% in middle altitudes in this state and by less than 10% in high altitudes; here even small isolated gains occurred (observed period 1951/52 - 1995/1996; Günther/Rachner 2000).

Besides these general retrospective trends, the focus of this chapter is on extreme weather events.

Extreme weather events

In this subchapter, a part of Germany's extreme weather event development in the past will be presented. In doing so, it should be mentioned that extreme weather events are not the only influencing factor for damages. What is also of great relevance are the population density and concentration of wealth in the affected area. Moreover, threats are determined more by the intensity than by the quantity of extreme weather events. Considering Germany, the increase in extreme weather events may be significant for the economy (UBA 2006).

For the detection of a possible change in extreme weather events, calculations have been made in order to identify the impact on the climate factors temperature and precipitation (UBA-EWE). For the changes in wind speed, a statistical robust effect could not be found (Schönwiese 2007). While temperatures follow a Gaussian distribution[4], precipitation may be described with a Gumbel-distribution[5]. When considering extreme events, the outer margins of the density functions are of interest, whereas "extreme" is often defined as lying outside the 1σ standard deviation (UBA EWE). According to this, the tendency to extreme events is mainly given as a temporal change of the probability to excess the 95% confidence interval (or to fall below the 5% confidence interval).

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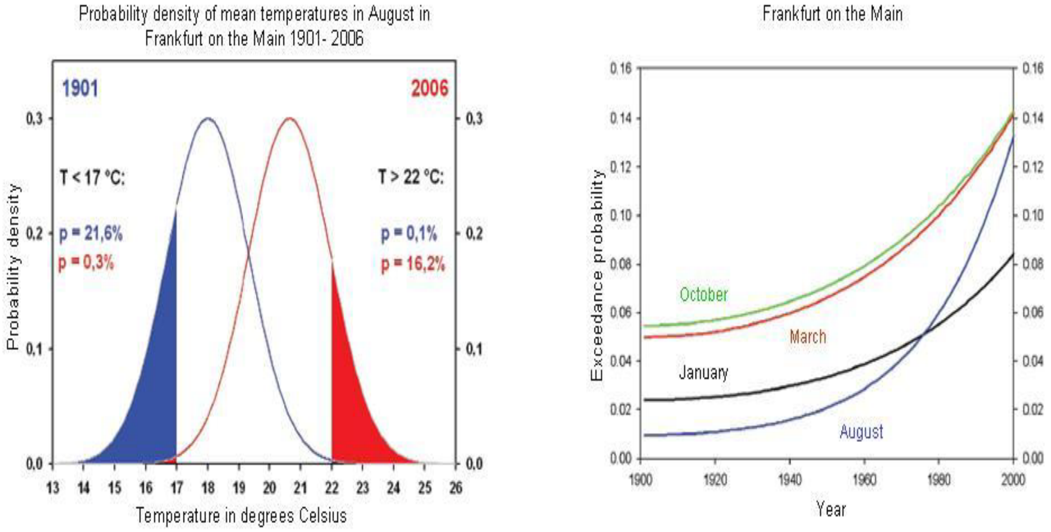
[3] Orography means the study of average relief and height structures of land.

[4] The Gaussian distribution (also called normal distribution) is a continuous probability distribution which is symmetrically distributed around a mean where the probability is highest. The graph of the corresponding density function is bell shaped and dependent on the values of the mean (mostly denoted as μ) and the standard deviation (σ).

[5] The Gumbel distribution is a continuous probability distribution which is asymmetrically distributed (positive skewness) around a mean where the probability is highest. The Gumbel distribution follows the cumulative distribution function $F(x,\mu,\beta) = e^{-e^{(\mu-x)/\beta}}$.

Figure 3: Shift of the density function of temperature distributions in Frankfurt (left), increase of the probability to exceed the 95%-percentile of the temperature probability distribution for selected months (right). Source: Schönwiese 2007.



Extreme temperature abnormalities

As shown in chapter 3.2 and also observable in

Figure 3 (left section), the average temperature has shifted towards higher values in the past. Therefore an increase of abnormalities in temperature could mainly be detected in reference to hot days during summertime. The graph shows the shift of the mean annual temperature for the city of Frankfurt from 1901 to 2006. Hence, the probability of the mean temperature to fall below a value of 17°C has decreased from 21.6% to 0.3%, but the probability to exceed 22°C has increased from 0.1% to 16.2%. This trend may be observed throughout Germany (Schönwiese 2007).

The right section of

Figure 3 specifies the mean annual values in regard to a seasonal view (Schönwiese 2007). It shows that the probability to exceed the 95%-percentile has more than doubled for October (5.5% to 14%) and increased thirteen-fold for August (1% to 13%). Consequently, extreme temperature events in the form of heat waves were much more likely to occur than mild weather conditions during autumn and winter due to increased temperatures.

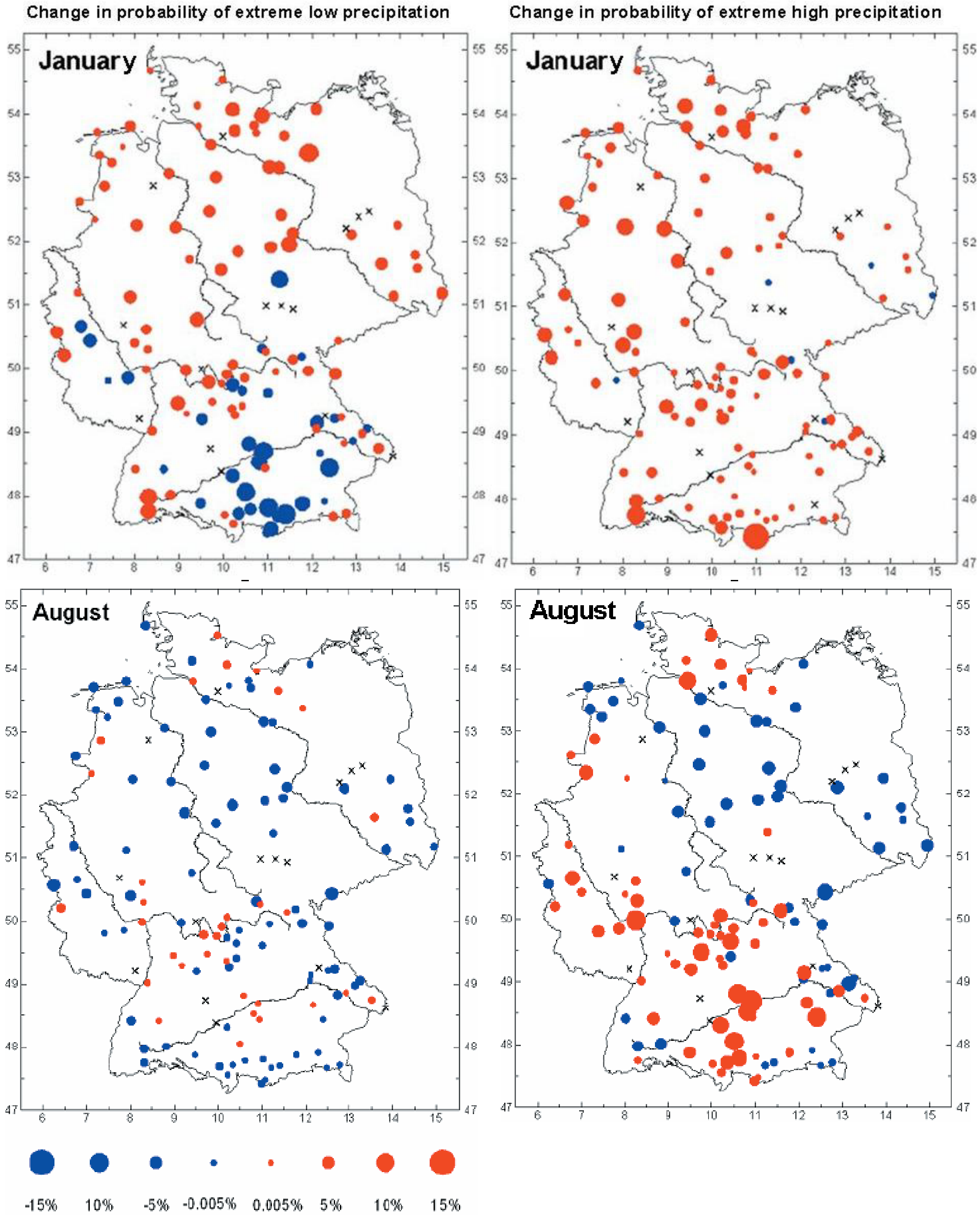
Despite the clear shift towards warmer temperatures with peak values in summer, no clear tendency to an increase in extreme temperature events (cold and heat waves) may be detected for the last century (UBA EWE).

Extreme precipitation

In comparison to temperature changes, which were more or less equally distributed across Germany, extreme precipitation events vary at a much higher scale. Thus, no general trend may be given, nor is it possible to state for the whole of Germany that precipitation or drought events have increased in general. The situation is different, however, from a local perspective: Figure 4 shows the precipitation trends for 1901-2000 during winter (above) and summer (below) in a regional dimension. During winter a significant occurrence of extreme events (below and above the 1σ-interval) may be observed throughout Northwestern Germany. In contrast, a strong decrease of extreme droughts occurred in South-Bavaria, simply spoken, precipitation became less volatile in that region.

The probability of extreme precipitation events during summer shows an even more inconsistent pattern. According to the trend, extreme droughts in summer became less probable. In contrary, a significant tendency to heavy rain falls and therefore an increased danger of flooding could be observed for southern Germany (Schönwiese et al. 2005).

Figure 4: Probability to fall below the 5%-percentile (left side) or to exceed the 95%-percentile (right side) of the precipitation probability density function for 132 selected sites.



Orange points on the right side symbolise an increase of the probability of heavy rainfall events. The upper part of the illustration presents the situation in January, the lower part in August. Black Xs stand for insignificant probabilities.
Source: Schönwiese et al. 2005.

Despite a slight threat due to extreme precipitation events, no clear evidence of a general increase in extreme events throughout Germany may be given in reference to precipitation either. Thus, the available data do not allow a robust statement regarding the long-term development of precipitation events on the national level. (Schönwiese 2007, Schönwiese et al. 2005).

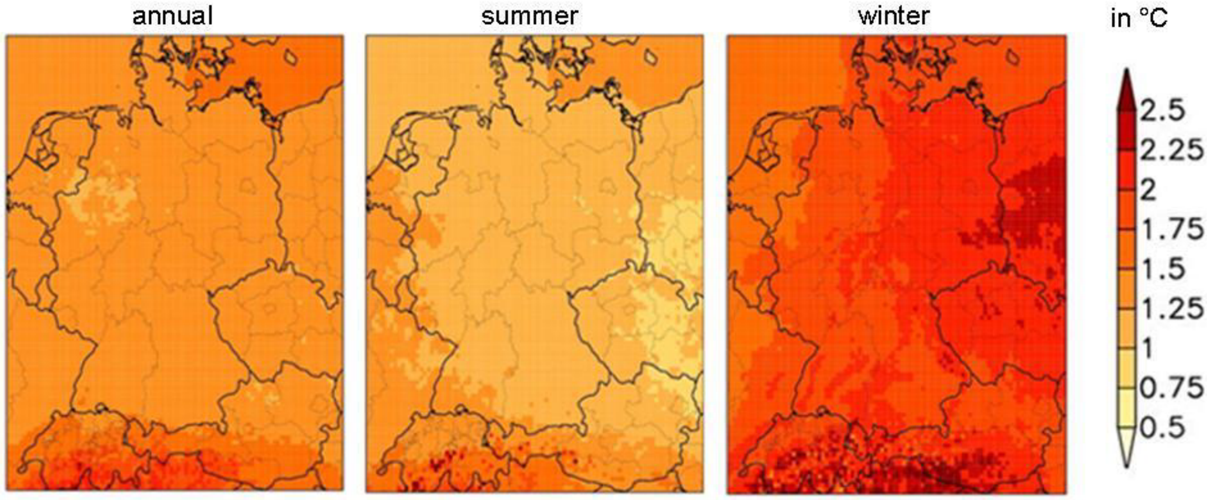
4.4.2. Climate change in the future

The Germany's Federal Environmental Agency has adopted two main approaches of regional climate models: WETTREG (UBA 2007) and REMO (UBA 2008). This chapter mainly concentrates on results of the REMO model, while results of WETTREG are described in a subsection of this chapter. REMO is based on a dynamic approach using the boundary conditions of the global model ECHAM5/MPI-OM. WETTREG uses a statistical downscaling approach of the same global model as REMO. Both models are based on the IPCC socio-economic storylines and their derived scenarios A2, A1B and B1 (representing high, middle and low emission rates of GHG). Publications on both modelling results are mainly given for the comparison period 2071-2100. REMO results until 2050 are available for the A1B scenario on http://www.mpimet.mpg.de.

4.4.2.1. Air temperature change

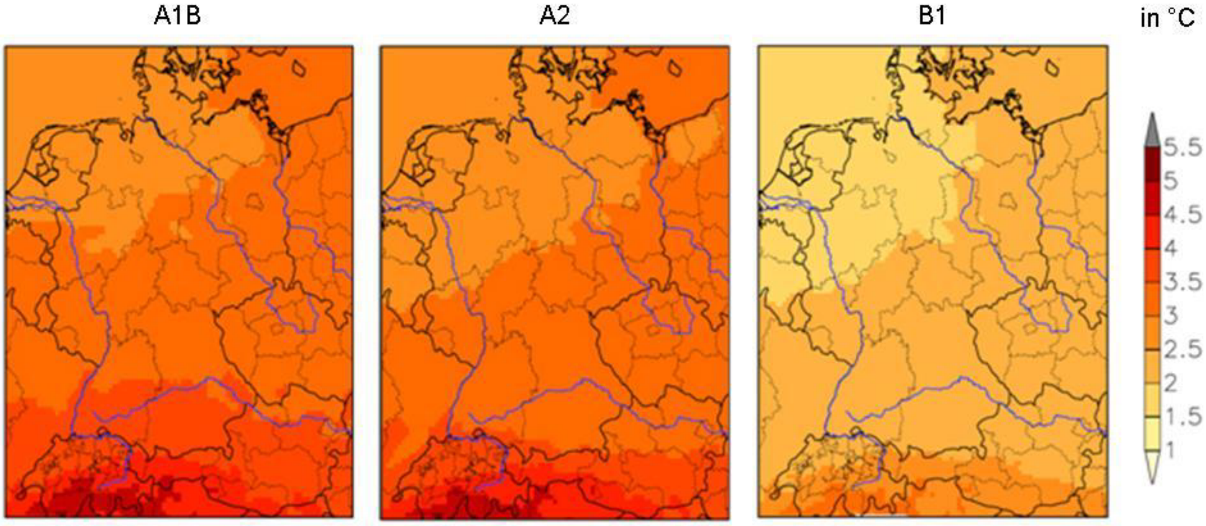
The climate scenarios are calculated with a resolution of 10km x 10km. Comparing the average of the period 2031-2060 with the average of the period 1971-2000 (scenario A1B), a relatively homogeneous annual temperature increase throughout Germany with approximately 1.25 to 1.5°C is expected (see Figure 5). In this context, a lower temperature change is estimated for the summer months than for the winter period. In winter, the temperature is expected to increase in large parts of Germany (particularly in the East) by more than 2°C by 2050. The trend of higher warming in winter will remain until 2100.

Figure 5: GHG-emission scenario A1B: Mean air temperature change, 2031/2060 compared to 1971/2000. Source: http://www.mpimet.mpg.de.



For the period after 2050, a more heterogeneous pattern of warming is expected, with the highest annual warming expectations for the South of Germany. By 2100, warming could increase by more than 4°C compared to the mean temperature during the years 1961-1990 (see Figure 6).

Figure 6: Mean air temperature change, 2071/2100 compared to 1961/1990. From left to right: IPCC-emission scenarios A1B, A2 and B1. Source: UBA 2008.

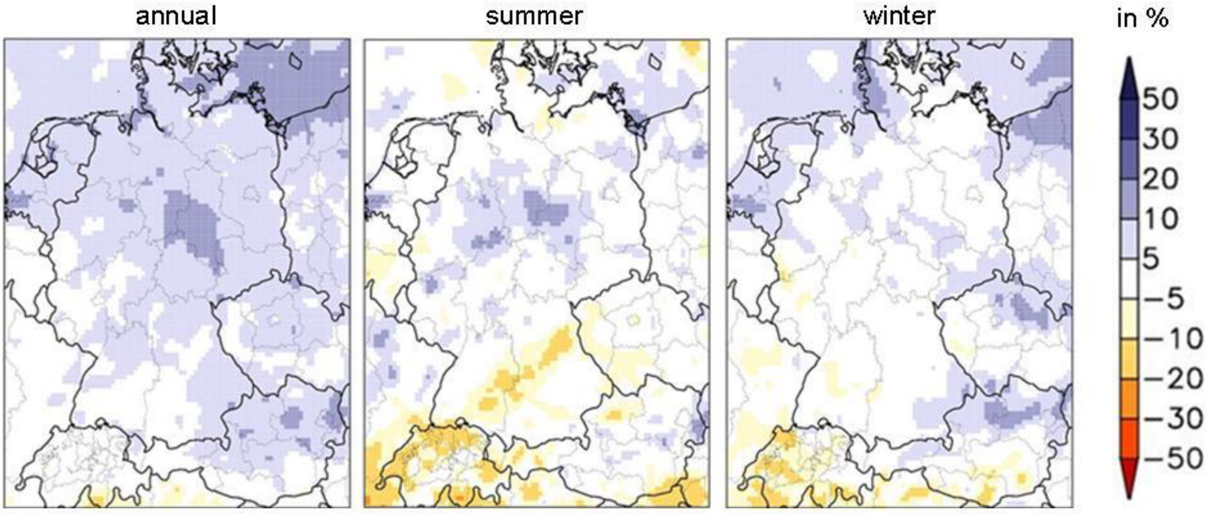


4.4.2.2. Precipitation change

The following section focuses on the results of scenario A1B, possible significant differences in contrast to results of other scenarios will, however, be mentioned.

During the summer months, the A1B-scenario estimates a decrease in precipitation by 10 to 20% in parts of Southern Germany and an increase in precipitation by 10 to 20% for Mid-Germany (Harz region). Winter precipitation remains relatively constant; only for the North Sea area (particularly Schleswig-Holstein) an increase by as much as 20% may be expected. The mean annual precipitation increases relatively homogenously by 5 to 10%. Only the Harz region and the coast show larger increases by 10 to 20% and some southern regions experience insignificant changes.

Figure 7: IPCC-Scenario A1B: Change in mean precipitation (in % of current precipitation), 2031/2060 compared to 1971/2000. Source: http://www.mpimet.mpg.de.



By 2100, mean annual precipitation increases may account for as much as 10% in some regions, whereas 20% increases are probable only in relatively small areas (e.g. the Harz). But overall annual precipitation balance remains relatively constant for all considered scenarios. Therefore the results of other scenarios are not explicitly illustrated.

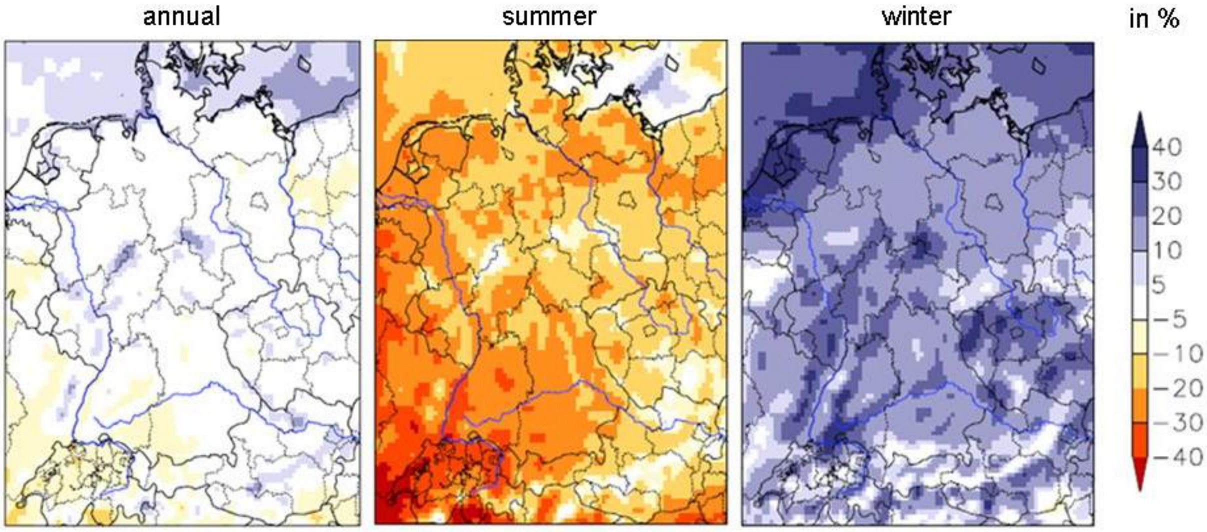
The picture changes significantly if seasonal patterns are considered. A shift of precipitation from summer to winter is estimated for all scenarios for the period after 2050. Besides, an increase in autumn and spring precipitation is projected until 2100. As shown in Figure 8, the highest decrease in summer precipitation could amount to 20 to 30% for large parts of Germany, particularly for regions in Bavaria and Baden-Württemberg. In some areas, even a decrease by 40% is possible, particularly throughout the Upper Rhine rift.

The winter precipitation estimates clearly predict increases concerning the period 2071-2100 as shown in Figure 8. The largest increases occur for the coastline and some parts of South-Western Germany. Some areas, particularly mountainous areas (e.g. the Alps) will probably experience no change at all.

The other scenarios calculate slightly higher precipitation levels throughout the year, which means larger increases in winter and smaller decreases in summer. Thus, the expected shift of precipitation from summer to winter remains also in the A2 scenario, which is not specifically illustrated here. A remarkable exception is the B1 scenario, which predicts more precipitation increases in spring and autumn than in winter – which means the shift is expected from summer to spring and autumn rather than to winter.

However, the spatial distribution of precipitation changes is fairly consistent across scenarios. Areas most affected by a decrease in precipitation in summer are the Upper Rhine Rift and the South-West, whereas the largest precipitation increases in winter are expected at the coast and in the low mountain range, particularly in the Harz.

Figure 8: Scenario A1B: Change in mean precipitation (in % of current precipitation), 2071/2100 compared to 1961/1990. Source: UBA 2008.



4.4.2.3. Extreme weather events

REMO defines and analyses four different forms of extreme weather events (UBA 2008): Windstorms (mean wind velocity > 10m/s), heavy rainfall events (daily precipitation > 25 mm), drought periods (daily precipitation < 0.1mm) and summer and heat days (summer days have a max. temperature of 25°C, heat days of 30°C).

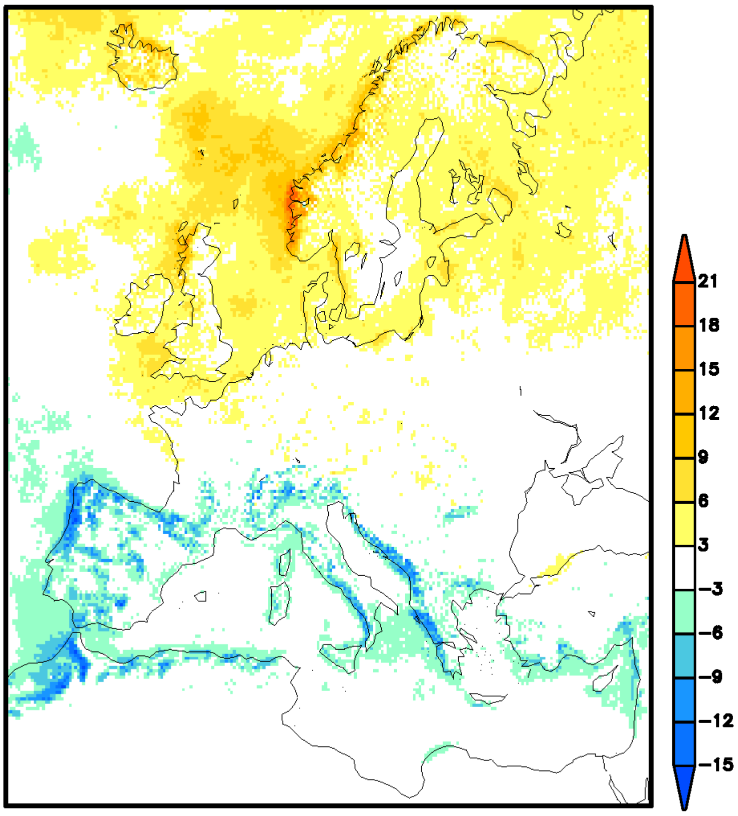
Since the studies are currently in process, further results concerning the probability of extreme weather events are likely to come. So far a significant change in windstorm and heavy rainfall events has not been simulated. Concerning droughts, a certain shortening of maximum drought periods in a year is calculated by REMO: For the years 1961 to 1990, an average maximum of a 10 days period for Northern Germany and 20 days period for Southern Germany were found. The scenarios B1 and A2 estimate a slight shortening of two to four days in average.

Summer heat days will be more affected by climate change according to the calculations: Until 2100 a strongly increasing trend with strong variations occurs. Scenarios A2 and A1B calculate that the amount of summer heat days may double up to 40 until the mid-century. Scenario B1 would reach this increase during the period 2060 to 2080. Today 4 to 5 days per year are accounted as heat days. The estimated number of heat days is 20 per year. However, variations between the scenarios are fairly high in this respect (B1 calculates only 8 heat days per year around 2070).

For the wind speed in Germany a slight increase of 0.3 m/s is calculated for some months until 2050 for all scenarios. Until the end of the century slight increases for the winter and decreases for some summer months are calculated.

The dynamic regionalisation model CLM does not only calculate summer and frost days, but also the occurrence of days with heavy precipitation. Figure 9 shows the calculated changes in the number of days with heavy precipitation in Europe. The map clearly demonstrates that, so far, no significant trend could be computed for Central Europe, in contrast to frost days and summer days, for which the trend calculated in CLM corresponds to the results from WETTREG and REMO.

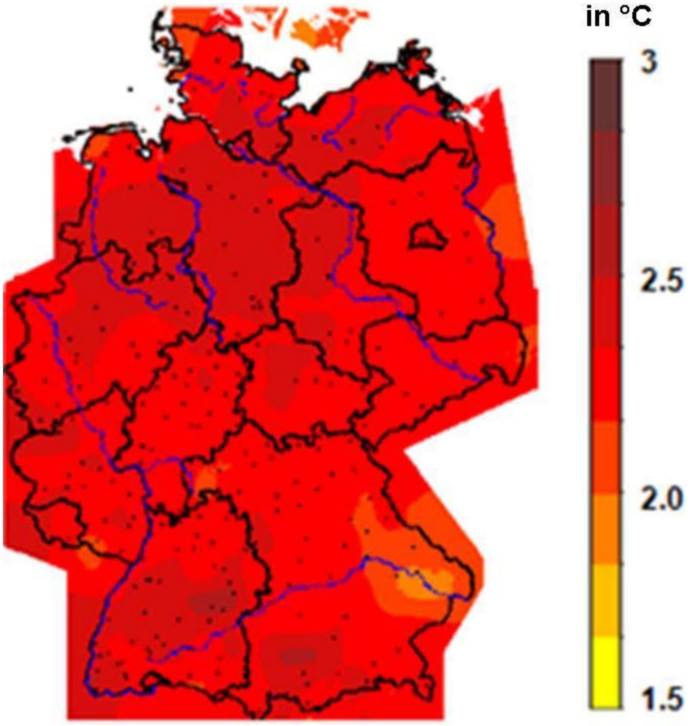
Figure 9: Changes in the number of days with heavy precipitation in Europe under IPCC scenario A1B, calculated using the regionalisation model CLM. Source: Böhm 2008.



4.4.2.4. A short presentation of WETTREG-results

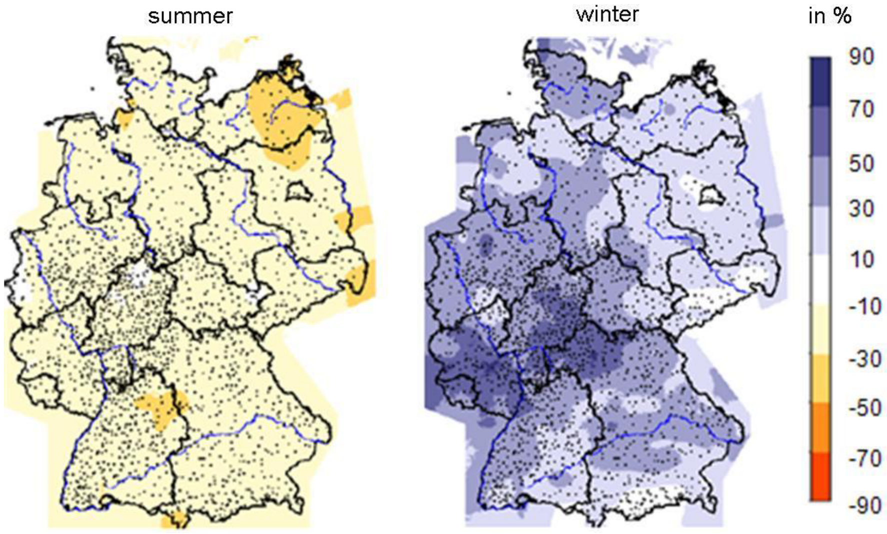
Like Remo, WETTREG also identifies a significant increase in air temperature. It calculates an increase of 2.3°C on average over the whole of Germany assuming the A1B scenario. Scenario B1 calculates an increase of 1.8°C. Compared to the REMO results, WETTREG shows different regional patterns until 2100, as illustrated in Figure 10 for scenario A1B. Scenarios A1B and B1 simulate a stronger warming in the North compared to the South. Until 2050, regional patterns of warming are calculated to be relatively homogenous.

Figure 10: Scenario A1B: Average daytime temperature change, 2071/2100 compared to 1961/1990. Source: UBA (2007).



The WETTREG approach simulates also the shift of precipitation from summer to winter as presented for scenario A1B in Figure 11. For scenarios A1B and B1, similar regional patterns are simulated by WETTREG. In the A1B scenario, however, the simulation estimates a smaller precipitation decrease in summer and a larger precipitation increase in winter than on the basis of other scenarios. The decrease in precipitation in summer for the whole of Germany until 2100 amounts to 22% for scenario A1B and 17.7% for scenario B1. The increase in precipitation in winter amounts to 30.3% for scenario A1B and 19% for scenario B1.

Figure 11: Scenario A1B: Change in mean precipitation (in % of current precipitation), 2071/2100 compared to 1961/1990. Source: UBA (2007).



An analysis for characteristic days[6] is carried out for A1B scenario and results are available at four different gauges: Arkona at the coast, Braunlage in the Harz, Freiburg at the Upper Rhine rift and Garmisch-Partenkirchen in the Pre-Alps. The results regarding the relative change in characteristic days are presented in Table 1.

Table 1: Relative amount of frost, summer and heat days in different regions of Germany in the decade 2091-2100 (1981-1990 = 100). Source: UBA 2007.

Region	Frost days (%) (1981-1990=100)	Summer days (%) (1981-1990=100)	Heat days (%) (1981-1990=100)
Arkona at the coast	**< 50**	**> 200**	**nonexistent**
Braunlage in the Harz	**ca. 60**	**> 200**	**> 200**
Freiburg at the Upper Rhine rift	**< 50**	**ca. 150**	**> 200**
Garmisch-Partenkirchen in the Pre-Alps	**ca. 70**	**ca. 170**	**> 150**

To sum up, frost and ice days are projected to decline and heat and summer days to increase for all gauges. Furthermore an estimate of changes in heat waves in Heidelberg (Upper Rhine rift) shows that the frequency as well as the length of the event will probably increase. Heat waves and tropical nights have a potential effect on human health (UBA 2007).

4.5. Impacts, vulnerability and adaptation measures in critical fields

The approach used is shown in Figure 12. To accomplish a systematic overview, the impacts of climate change are pictured within critical fields. Individual chapters introduce the specific characteristics of the field, then point out potential impacts and highlight vulnerable regions using the environmental zones presented in chapter 4.2. According to UBA (2005), vulnerability is defined as the vulnerability to climate change with a minor focus on socio-economic changes. Vulnerability is classified as low, moderate and high. The term is furthermore based on the *current* status, omitting further (intended) adaptation measures improving the vulnerability status on the one hand or possible deterioration on the other. In contrast to the illustration of regional vulnerability, the adaptation measures pictured here are generally valid for all regions and German states. Exceptions are named explicitly. Adaptation is divided into autonomous and planned adaptation. Most adaptation measures presented in this case study have a private-good character. The self-interest of individuals provides incentives to take measures that reduce potential damages or to increase benefits (e.g. in agriculture due to changed crop choice) induced by climate change. In this context, autonomous adaptation, to be adjusted to markets, is preferred for efficiency reasons. However, some adaptation measures have a public-good character and therefore have to be provided by public authorities (e.g. flood protection measures). This planned adaptation is necessary for three reasons: Government intervention due to market failure, because of distributional aspects and for security of supply rationales.

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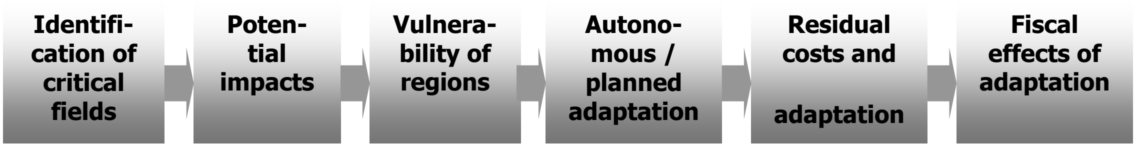
[6] Characteristic days are specified by the following criteria: Ice days are defined as days per year with maximum temperatures ≤0°C; frost days as days with minimal temperatures ≤0°C; summer days as days with maximal temperatures ≥25°C; heat days with maximal temperatures ≥30°C; tropical nights as nights with minimal temperatures ≥20°C.

Reasons for market failure may be negative as well as positive externalities and asymmetric information distribution. Having identified possible planned adaptation responses, the present study tries to quantify the costs by gathering available information from the literature. These total costs of adaptation then can be split up into private costs and public costs, which pose the additional fiscal burden on the public budgets.

Critical field-specific impacts and consequential adaptation measures are summarised in tables at the end of every subchapter. It must be stated that even if all mentioned adaptation measures would be realised, there will be residual damages that occur in spite of adaptation. In some fields they are negligible, e.g. in the case of sea level rise in Germany; in others, like in the field of water scarcity in summer, adaptation can only marginally mitigate or prevent the expected impacts.

The critical fields mainly refer to economic sectors, but also the economically hardly comprehensible field of water supply will be pointed out in the following section.

Figure 12: The approach scheme applied in chapter 4.5.



4.5.1. Changes in inland water balance and sea water

This chapter deals, on the one hand, with inland water balance. Effects of water shortages during summer and river floods are considered. Besides, the quantity of available (drinking) water is important as well as the change in quality, which may be considered to only a limited extent. On the other hand, the effects of a possible change in the mean sea level will be discussed. The focus is on sea level rise and storm surges.

4.5.1.1. Inland water balance and water supply in summer

Exposure

Water surfaces (rivers, natural lakes and water reservoirs) account for 2.2% of Germany's total surface. 11.7% of the surface is classified as drinking water protection area and is subject to restrictions of use in order to protect existing water resources. The water availability is closely connected to the water balance (precipitation minus surface evaporation). Thus, besides climatic conditions, the water balance is highly dependent on the type and condition of the surface. Evaporation and ground-sealing[7] worsen infiltration into the ground. As shown in Figure 13, large parts of East Germany have a negative water balance throughout the year. The highest deficits occur in the Eastern foreland of the lower Harz and in the Oderbruch[8]. In contrast, the Alps and the low mountain ranges achieve the highest positive rates in water balance. On the demand side major water use is carried out by the public energy sector with

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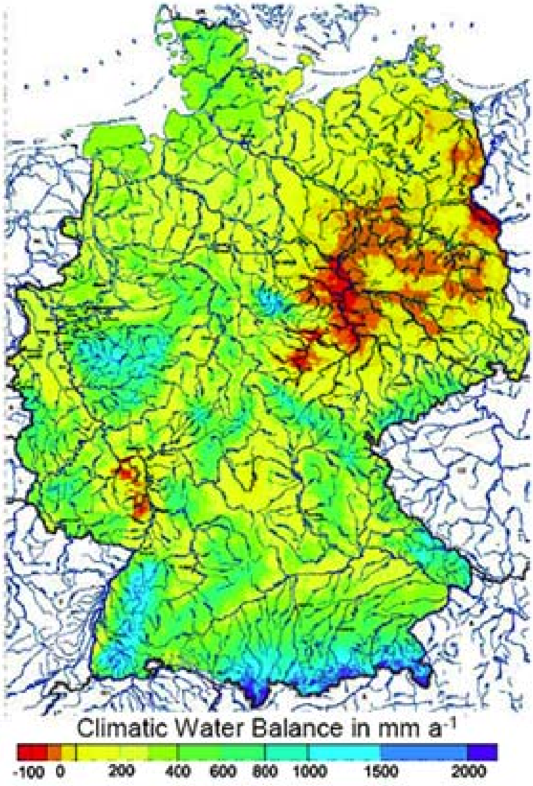
[7] Here ground sealing essentially refers to sealing of natural ground by buildings or asphalt surfaces.

[8] The Oderbruch is an inland delta, a marshland between the state Brandenburg and Poland.

56% (for cooling), followed by mining and industry with 18% and public water supply with 13%. Agriculture and forestry have a share with less than 1% in water demand (UBA 2005).

Figure 13: The climatic water balance of Germany. The colour range from yellow to blue indicates a positive water balance. Red colouring indicates a negative water balance. Source: UBA 2005.



Climate change impacts

The changes of precipitation discussed in section 4.4.2 lead to a spatially and quantitatively redistributed pattern of water availability. Besides the changes of sub terrestrial water reservoirs which will not be considered here, this leads to changes in river drainage regimes and run-off rates. Models[9] estimating the change in annual and drought minimum run-offs come to indefinite conclusions for Germany concerning alteration until 2050. But the summer run-offs (June-August) show a clearer pattern with less water availability by up to -25% until 2050 throughout Germany. The reasons are the shift of precipitations from summer to winter on the one hand and increased evaporation due to higher temperature one the other. Besides, higher herbal water use due to the elongation of the vegetation period and the alteration of the snow cover in winter is not included in this consideration. Further examinations are needed concerning this field (UBA 2005).

Figure 14 depicts calculations by the Potsdam Institute for Climate Impact Research (PIK) with respect to river discharge at a measuring point at the lower Elbe compared to the

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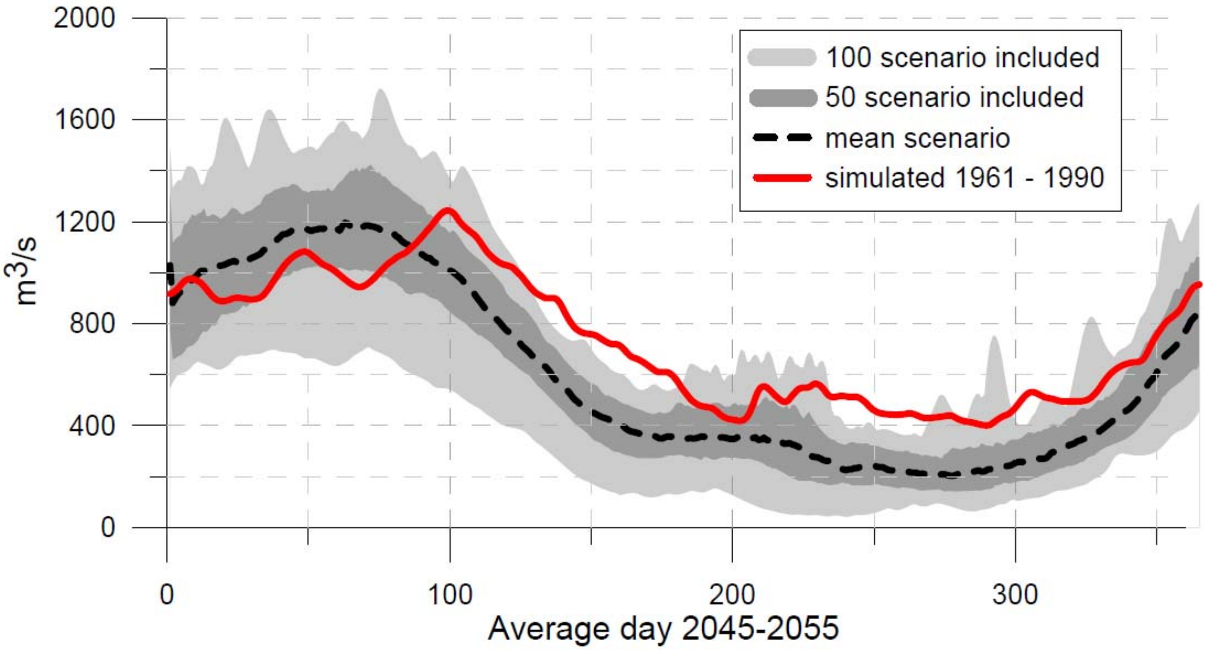
[9] The results originate from the ATEAM-project, assuming seven different model-scenario combinations (UBA 2005).

reference situation 1961-1990. According to these calculations, the average discharge of many years decreases in 100% of all scenario calculations within several weeks.

Figure 14: River discharge at the lower Elbe (gauge at Neu-Darchau, exact to the day), mean value from reference scenario 1961/1990; distribution of mean values from 100 scenario calculations.



Vulnerability and Adaptation

The heat wave in 2003 demonstrated the damages likely to be caused by above-average temperatures and water shortages. Harvest losses in agriculture and forestry were high. Besides, there were constraints for the inland water transport and for thermal as well as water power plants. These effects are clearly presented in the following chapters. However, the drinking water supply was not threatened. This event may possibly not have a link to climate change but shows the potential vulnerability of Germany to water imbalances.

The extent of vulnerability will undergo an increase during the next decades: Today, aside from temporary and regional deficits and singular extreme events, the current water supply is regarded as adequate (Leibundgut and Kern 2006). In the future, the vulnerability to drought risks is particularly high for East Germany (North-East German lowland and South-East German basin and hills). As shown in Figure 13 the region has already today an adverse water balance, and scenario-based estimates assess further temperature rises (therewith increases in evaporation) and decreases in precipitation during summer as described by REMO, particularly after 2050. The Alps, the central low mountain ranges, the North-West German lowland and the coastline show a low vulnerability, according to the vulnerability assessment report of UBA (2005). Moderate vulnerability is identified for all other environmental zones. For the vulnerability of the Alps, CIPRA (2004) comes to a different conclusion, stressing the high vulnerability of the Alpine water regime. The observed global warming has always been exceeded by the regional warming in the Alps, with severe consequences for the snow cover and snow reliability. Precipitation in liquid form will run off faster than snow and ice. Hence, although the annual amount of precipitation is not expected to change so much in the Alps, the warming may influence the water balance by snow and ice cover.

In the past an autonomous adaptation measure by consumers and companies took place. Although not linked to shortages in water supply, the increase of water prices in the past led to a change in consumer behaviour and modified production techniques and therefore decreases in water demand (UBA 2005). Water-saving as an autonomous adaptation can be also expected for the future, if prices increase further as they did in the past. However, by far most adaptation measures here are planned, since they often refer to the publicly organised service of water supply and land use management. As for infrastructure investments in water supply and sewage systems, Bräuer et al. (2009) assume an additional financial burden on the public budgets of 10-190 million € p.a.. However, these figures are based on quite questionable assumptions which cannot be tested due to a lack of data.

In Table 2 probable adaptation measures on the public level as well as private level are listed. Regarding the effect of possible adaptation measures, it should be mentioned that many impacts are virtually unavoidable. Agriculture, forestry and inland water traffic will suffer from enduring droughts even if all these adaptation measures are considered, which emphasises the need for these sectors to provide for the risks of water scarcity (e.g. by drought insurance or risk diversification).

Table 2: Autonomous and planned adaptation measures concerning water supply in summer.

Impact	Adaptation measure	Autonomous		Planned	Nature of adaptation	
		Consumer	Producer	Public	Proactive	Reactive
Impairment of water balance (groundwater level)	Enlarging awareness to water-saving of the consumers			X	X	
	Reconsidering land use management			X	X	
	Increased responsibility in the use of water	X			X	
	Coordination with other sectors			X	X	
	Increased monitoring on water quality			X	X	
	Implementation of a substantial land use management			X	X	
	Infrastructural measures (e.g. sufficient storage of water in impounding reservoirs)			X	X	
	Restriction on water use			X		X

4.5.1.2. River floods

The main triggers for floods are heavy precipitation events as well as snow melting (Bartels et al. 2005). Furthermore, the amplitude and frequency of flood events is determined by many control factors, e.g. man-made regulations of the stream course, conditions of infiltration, characteristics of the runoff regime and particularly the loss of floodplains and wetlands as areas of retention in the past. The river Rhine has already lost four-fifth of its natural floodplains and river regulations shortened the run length by 100 km at the Upper Rhine and the Lower Rhine. The river Elbe only remained 14% of the natural floodplains and the run length lost 55 km on the Czech territory and 20 km on the German territory (UBA 2006a).

The co-operation project "climate change and consequences for the water management" (KLIWA) analyzes, *inter alia,* how floods occurred in the past and how they would develop until 2050 for Baden-Württemberg and Bavaria. Current hydrological research has not found any significant results for the long-run. But a trend to a more frequent appearance of floods and an increase in flood water flows, particularly for the winter period, was found for the past two to three decades. The natural margin of the water level is thereby exceeded (Bartels 2005). Analysis of the future development for the rivers Neckar and Rhine show a rise in flood water flows until 2050, particularly during wintertime. For example small and medium scale floods are assessed to rise by 40-50% for the Neckar area (Katzenberger 2004).

Vulnerability and adaptation

The risk of future river floods is identified as high for the whole of Germany, if no countermeasures are taken. Although in the federal regulatory framework measures are implemented to encounter flood risks (e.g. the 'act to improve preventive flood control'), climate change and its effects on flood risks are not yet embedded in this legislation.

Baden-Württemberg and Bavaria have implemented a technical flood protection measure for currently running projects based on the KLIWA results. A so called 'climate change factor' has been added to the critical runoffs, which are relevant for the planning of flood protection structures. As shown in Figure 15 the climate change factor in Baden-Württemberg is determined by the spatial mapping (the state area is split into five regions, each with a uniform climate change factor) and the annuality[10]. The added amount to the critical runoff accounts 15 to 25% for an annuality of 100 years depending on the region. If the flood event is expected to occur more often, the added percentage is higher. For Baden-Württemberg particularly the increase of small and medium size floods is expected. Bavaria adds lump-sum 15% on flood water flows of an annuality by up to 100 years. Thereby an alternative factor for a region can be decided with a reasonable explanation (Hennegriff et al. 2006).

Public authorities which plan precautionary flood prevention measures will have to tackle one further problem mentioned in Part I in section 2.2 (part on "Joint adaptation"). Dikes, levees and other constructed inland flood protection in up-river communities will mostly interfere with the flood risk in down-river localities that is they have negative externalities. Moreover, so-called "soft" flood protection techniques like the recreation of retention areas will mostly have positive external effects on down-river communities, while great areas in up-river locations are flooded. In these cases a superior institution is necessary which coordinates the distinct measures, otherwise it is very unlikely that a socially efficient outcome can be reached.

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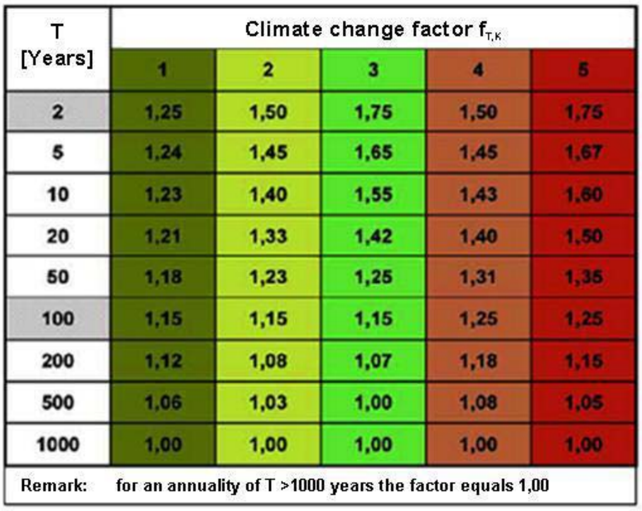
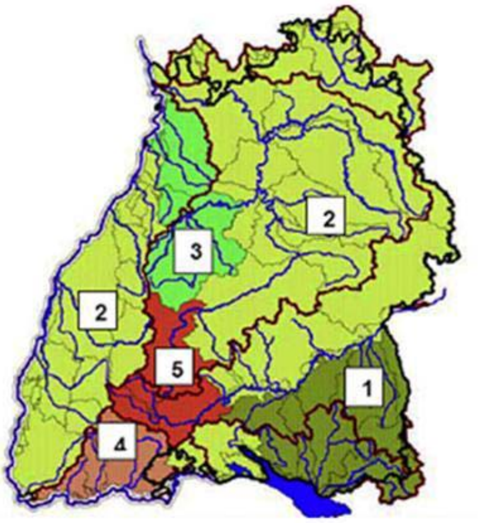
[10] The term ‚annuality' describes the time period for the recurring of a single event. For example a river flood with an annularity of 100 will occur on average once in 100 years.

Figure 15: Regions in Baden-Württemberg with uniform climate change factors. Source: Hennegriff et al. 2006.



T [Years]	Climate change factor $f_{T,K}$				
	1	2	3	4	5
2	1,25	1,50	1,75	1,50	1,75
5	1,24	1,45	1,65	1,45	1,67
10	1,23	1,40	1,55	1,43	1,60
20	1,21	1,33	1,42	1,40	1,50
50	1,18	1,23	1,25	1,31	1,35
100	1,15	1,15	1,15	1,25	1,25
200	1,12	1,08	1,07	1,18	1,15
500	1,06	1,03	1,00	1,08	1,05
1000	1,00	1,00	1,00	1,00	1,00
Remark:	for an annuality of T >1000 years the factor equals 1,00				



An important autonomous adaptation measure is the use of insurances. Since 1994, flood risks can be insured by private households and companies within an insurance against natural hazards in Germany. Until today this option was exercised only marginally: Natural hazard insurance is included in only 3.5% of the building insurance contracts and 10% of the contents insurance contracts. Thereby, premiums are classified by exposure into four categories[11]. The reason is twofold: Consumers evaluate insurance premiums as too high (particularly in highly endangered regions); moreover they rely on public relief. Furthermore, the law of large numbers cannot be applied in catastrophic events which affect many insured at one time. Thus, the reason for the market failure in insurance markets is an insufficient risk awareness of the population combined with adverse selection at the demand side and risk-averse insurance suppliers.

Both mentioned adaptation measures (climate change factor and insurance) show the broad range of possible adaptation means: Firstly there are measures that are to reduce the vulnerability by preventing floods in exposed areas, and secondly there are measures to reduce the individual economic damage so as to make it bearable by insurance or other means that reduce the adverse impacts if a flood happens. The former mainly depend on public activities such as flood protection infrastructure, while the latter is often an issue of private precaution. However, the example of purely market-based insurance schemes leaves some questions whether autonomous adaptation in the field of flood precaution is efficient in the sense of minimizing the expected total damage[12]. Possibly private agents underestimate their individual flood risks. This leads to the question whether the state should intervene by introducing a compulsory private insurance scheme for households, subsidise the insurance contracts or continue to grant ad-hoc relief. In Germany this discussion is still ongoing and without results to date.

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[11] The category 4 is assigned to a flood probability of once in 10 years, category 3 of once in 10 years to 50 years, category 2 of once 50-200 years and category 1 for residual areas.

[12] Expected total damage here refers to expected gross flood damage per year plus autonomous flood adaptation by flood adapted building plus insurance premiums.

With regard to river floods, the fiscal effects of extreme weather events may become of relevance. Lis and Nickel (2009) have examined the impact of extreme weather events on budget balances and come to the conclusion, that in contrast to developing countries, the budgets of advanced countries are not so clearly influenced by the occurrence of extreme weather events. They do not focus on floods or any other specific meteorological or climatic event or any special sector, but aggregate all possible extreme weather events and quantify the overall impact by econometric methods. For the group of EU countries, they do not find a significant influence of extremes on the budget balance. This finding has to be kept in mind for all sectors and all three analyzed countries. However, if the magnitude and frequency of extremes is going to increase, as projections suggest, also the budgets of advanced countries might get under significant influence (Lis and Nickel 2009). Adaptation measures are illustrated in Table 3.

Table 3: Autonomous and planned adaptation measures concerning river floods.

Impact	Adaptation measure	Autonomous		Planned	Nature of adaptation	
		Consumer	Producer	Public	Proactive	Reactive
River floods	Recreation of retention areas			X	X	
	Expansion of water supply and sewage networks			X	X	
	Improvement of flood protection infrastructure			X	X	
	Awareness building			X	X	
	Property construction out of risk area	X	X		X	
	Development of early-warning systems comprising regional particularities		X	X	X	
	Rethinking of land use in endangered areas			X	X	X
	Evacuation of flood endangered areas	X		X		X
	Flood adapted building	X	X	X	X	
	Flood Risk Management			X	X	
	Emergency Management			X		X
	Evaluating dam safety			X	X	
	Evaluating drainage systems			X	X	
	Including flood risks in insurance contracts	X	X		X	
	Coordination and Co-operation with neighbouring authorities			X	X	
Nutrient leachate into water reservoirs	Monitoring measures and reconsideration of fertilisation legislations			X	X	

4.5.1.3. Sea level rise and coastal floods

Germany's coastline

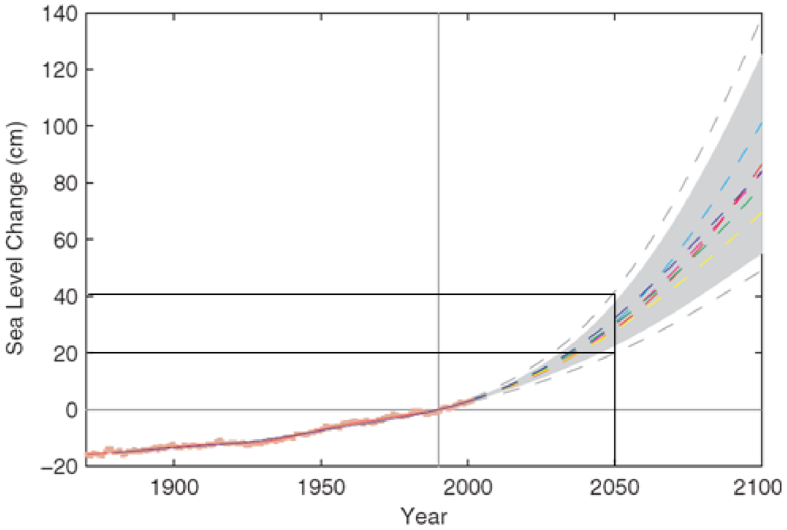
Germany coastlines extend along both the North Sea and the Baltic Sea. The North Sea coast has a length of approx. 1,590 km and the Baltic Sea coast a length of approx. 2,110 km, making a sum of 3,700 km. Since approx. 70% of the North Sea coast and 55% of the Baltic Sea coast are threatened by denudation and degradation (mainly sandy coast, especially the Frisian Islands), coastal protection is an important issue, also due to the important function of many coastlines to serve as protection against inland flooding c.

Dikes have played an important role as additional protection against storm surges. Because of steeper coastlines and smaller tidal ranges, only 27% of the Baltic Sea coastal areas must be protected by dikes, mostly the densely populated areas. 85% of the coastline of the North Sea is protected. The overall probability of floods accounts 1 per 100 years at the North Sea coast and between 1 per 250 years and 1 per 1000 tears for the Baltic Sea coast (Sterr 2008). Therefore the major part of the German coastline is endangered by storm surges and sea level rise.

Sea level rise

In the 20th century the annual global sea level rise (SLR) lay between 1.5 and 2 cm per decade. During the last years a rise of 3 cm per year was observed (WBGU 2006 pp. 1-4). Uncertainties calculating future SLR are serious. Beside the calculation of thermal expansion of water due to higher water temperature and changed water storages on land (e.g. ice in mountain glaciers), the melting of ice sheets exhibits the highest uncertainty and simultaneously the highest risk potential. If only the Greenland Ice Sheet would melt, sea level would increase by 6 to 7 m (Woth and Storch 2007). Rahmstorf (2007) has calculated the future SLR based on the past relationship between temperature and global SLR. Thereby his estimations are higher than the ones of the IPCC's Fourth Report (2007) on global SLR change. Until 2100 the report estimates a SLR by 18 to 59 cm for the period 2090-2099 relative to 1980-1999, inter alia not including the full ice sheet uncertainty. Past observed changes in sea level are thereby underestimated by the model. Rahmstorf (2007) calculates a SLR by 0.5 to 1.4 meters until 2100 relative to 1990 as seen in Figure 16. Until 2050 he calculates a rise by 20 to 40 cm. The North Sea could thereby experience a higher increase by 10 to 15 cm because of changes in water density and different patterns of sea currents until 2100 (Woth and Storch 2007). Moreover, since the last ice age the Northern Sea and Baltic Sea coastline descends by 1.5-2.5 mm per year in the long-run, which increases the relative local SLR (Sterr 2007).

Figure 16: Past and future sea level rise according to Rahmstorf (2007), based on the global projections of the IPCC Third Assessment Report.



The gray uncertainty range spans the range of temperature rise by 1.4 to 5.8°C. The dashed gray lines show the added uncertainty due to the statistical errors. Source: Rahmstorf 2007.

Storm flood events

Until 2050 a more threatening impact seem to be storm surges as SLR is relatively controllable with technical adaptation measures in Germany. Furthermore, storm surges are also the more severe danger for human lives than a steady but relatively predictable SLR.

No clear conclusion can be given for strong and extreme storm flood events in the past since no long data series are available, but an increase in the frequency of moderate storm floods is statistically ensured. Particularly, an increase in storm surges over the current century cannot be excluded (Sterr 2008). An essentially important condition for storm floods is a wind surge pushing the water masses into the coastal areas. The occurrence of spring tides amplifies the effects. Alone because of the relatively ensured SLR also a rise in storm surges can be expected. In the future wind speed would increase after calculations by Storch et al. (2007) by up to 10% until the end of the century for the winter half year. This would make an increase of 1% per decade (overestimating the effect in the first decades). The authors state that because of these small increases, rise in wind speed can currently not be proved but also not rejected, and they calculate future storm surges for St. Pauli and Cuxhaven. Therewith they point out the high uncertainty of the estimation. Until 2030 a rise of 10 to 20 cm is calculated for both cities, for 2085 much higher numbers with 50 to 60 cm in Cuxhaven and 50 to 80 cm in St. Pauli are estimated (assuming scenario A2, compared to the values of the end of the last century, thermal expansion of water included).

Hallegatte et al. (2008) distinguish between direct and indirect costs of a storm surge event. While direct effects are land and infrastructure losses, losses of human lives etc., indirect effects comprise job and production losses and reconstruction measures. For the city of Copenhagen they come to the conclusion that indirect effects are of minor importance in the cases of light storm surge events – at least in comparison to other exposed cities in the world. For a German city, a comparable study is not available yet.

Vulnerability and adaptation

Tol et al. (2008) have compiled the current level of sensitivity, awareness and implementation as well as intended adaptation measures for European countries. They conclude that for the German North Sea and Baltic Sea region large impacts on the coastal zones have to be expected, in particular on the coastal ecosystems. However, the consequences for people and economy are categorised as low, due to a currently high standard of coastal protection infrastructure. They based their rating for Germany on Sterr (2008). Sterr assesses the landward boundary of coastal zones threatened by storm flood events to be the 10 m contour line above the current sea-level at the North Sea and the 5 m contour line above current sea-level for the Baltic Sea if sea level would rise by 1 m. These values apply by the year 2100. The total size of the covered surface is more than 15,000 km², thereby the major part of the surface belongs to the North Sea coastal area. The whole surface accounts 4.2% of Germany's territory, the surface bounded by the 5 m contour line accounts 3.8% (Sterr 2008). Another paper by Sterr (2007) features boundary values for an earlier time horizon: Assuming the endangered surface area laying below 5 m a.s.l. at the North Sea and below 3 m a.s.l. at the Baltic Sea, this would make an area of 13,900 km^2, in which 3.2 million people currently live. The economic value in this area accounts more than 500 billion € (Sterr, 2007). Moreover Hofstede (2008) states, that further assets are still accumulated in coastal flood endangered areas. These infrastructural assets as well as land property are mainly in danger due to a steady SLR, while storm surges endanger also human lives.

In a recent study by Costa et al. (2009), the adaptation costs of hard adaptation measures to resist a one in hundred years storm event are estimated and compared to the estimated avoided damages of such an event. The authors conclude that for Germany the benefits clearly exceed the costs in the long term (by the end of this century). According to them, there would be a cumulated net benefit of adapting to a one in hundred years event of more than 1% of the 2007 German GDP, by 2100.

On a scale from very low to very high, Tol et al. (2008) have classified Germany's awareness as high. Implemented adaptation measures are monitoring of SLR, coastal climate and the erosion of the coastal zone. Because of their disputed sufficiency, the current regulations are under reconsideration. In this process, some specific conflicts due to the federal structure of Germany may occur. In Germany, the federal states are responsible for the coast protection, but the central administration can bear 70% of the investment costs of new measures. The federal states have to pay the full maintenance costs. The protection programs of the federal states in the period 1998-2015 have a value of 2.6 billion €. Hamburg has the highest annual costs with 600 million € in 22 years (ca. 27 million €/year). The quite high capital accumulation near the coast requires a high level of protection. The cost protection is prepared for a 1/400 event (an event which probably happens one time in 400 years); in the federal state Schleswig-Holstein the level of protection is designed for a 1/100 event (Policy Research Corporation 2009).

According to Bräuer et al. (2009), the infrastructure costs for heightening dykes and other coastal protection structures rise by 10 million € p.a. per 10 cm sea-level rise, by assuming a (simplifying) linear relationship. Sea-level rises of 20-30 cm by 2050 thus would translate into additional fiscal costs of 20-30 million € p.a., or 100 million € p.a. up to 2100 respectively. The authors also evaluate the residual damage costs of storm surges for Germany and estimate a total damage of 1.25 million € p.a. in the middle of the century and up to 3.75 million € p.a. towards the end of the century. Although not directly referring to adaptation costs, a deeper view on these damage costs can be interesting for the methodology determining how to share the burden between the public and private budgets. Therefore the event of the Elbe flooding in 2002 serves as an example. At that time 45% of the total costs were borne by the government, mainly through flood relief payments. Due to lack of further information, the same ratio is assumed for the future, which would result in an extra fiscal burden of approximately 600.000 € p.a. around 2050 and 1.7 million € p.a. around 2100 just for storm surges. It should be stated that these are only the direct effects of a storm surge, possible indirect effects through production losses (and thereby induced loss of income and tax revenue) or more efficient alternative investments instead of reconstruction are not considered. However, these indirect effects on the tax revenues are by nature difficult to estimate in quantitative terms.

Since flood protection is a task of the federal states and not of the central administration, there can be disputes between the states about the optimal height of dikes. One state administration may evaluate uncertain climate projections in a different way than the neighbouring state administration. This would, without negotiations, result in the lower protection solution. Regarding the costs of hard adaptation measures, the experience in building and existence of coastal infrastructure are advantageous since one can build upon existing structures. This also implies that in the case of SLR, adaptation measures in Germany clearly concentrate on preventing storm surge damages (by dike constructions) rather than mitigating the economic damages (by flood adapted building) or distributing the economic losses (e.g. by insurance).

In general, it can be stated that with adapted flood protection infrastructure, the residual damages of a SLR are expected to stay small in Germany. Moreover, some of the available estimates show that in Germany, additional adaptation to a sea level rise and storm surges is not that expensive due to a high capital stock which is already in place. These sunk costs are not considered in this study, although one can argue they should be counted as adaptation costs. This might be of particular relevance when comparing the vulnerability of Germany with other European countries which are not so well equipped. These and other adaptation measures are summarised in Table 4.

Table 4: Autonomous and planned adaptation measures concerning coastal floods.

Impact	Adaptation measure	Autonomous		Planned	Nature of adaptation	
		Consumer	Producer	Public	Proactive	Reactive
Increase in coastal storms and sea level rise	Construction and heightening of dykes and other coastal protection structures			X	X	
	Spatial Planning, prohibition of building, near the coastline			X	X	
	Monitoring of SLR, coastal climate and the erosion of the coastal zone			X	X	
	Reconsideration of current regulations			X	X	
	Awareness building of the population			X	X	
	Evacuation of flood endangered areas	X	X	X		X

4.5.2. Agriculture and forestry

4.5.2.1. Basic outline

Forests account approximately for one third and agricultural area over 50% of Germany's territory (UBA 2005). The share of agriculture and forestry in GDP accounts for little more than 1%. 70% of the agricultural land is used for crop production, 29% as grassland and 1% as area of vine cultivation (Statistisches Bundesamt, Datenreport 2006). Germany is beyond France and Italy as the biggest producer of agricultural products in the European Union. Concerning agriculture, the focus of this study is laid on crop production since impacts of climate change on livestock husbandry is little discussed. The suitability for agricultural use is spread heterogeneously over Germany. Most areas are of intermediate to good soil-quality. The best conditions for agriculture are based on the loess soils of the plains ("Börde") of Magdeburg and Lower Saxony, as well as on the soils of the Upper Rhine rift. The sandy and poor soils in Brandenburg and the "Geest" landscapes of North-western Germany show the lowest suitability. In the future, lowering of market supporting measures and liberalisation of prices will have considerable socio-economic consequences to German farmers and will therefore influence the sector substantially. Consequences are thereby discussed controversial, but the majority of experts expect a decline in agricultural areas and a concentration on regions remaining economically viable (UBA 2005).

3.4 million m^3 of wood makes Germany the biggest reservoir of wood in Europe (BMELV 2008). The federal states with the highest share of forest area in total territory are Rhineland-

Palatinate and Hessen with over 40%, Baden-Württemberg with 39% and Bavaria, Saarland and Brandenburg with approx. 35% (MLR 2009) Norway spruce (Picea abies) is the economically most important tree with 28% holding in whole forest area; followed by Scots Pine (Pinus sylvestris) with 23%, common beech (Fagus Sylvatica) with 15%, and common and sessile oak (Quercus robur and Q. petraea) with 10%. 46% of the forest is privately owned, 34% are owned by the federal states or the federal government, and 20% by towns, communities and other corporate bodies (UBA 2005).

4.5.2.2. Climate change impacts on agriculture and forestry

Agriculture and forestry are the sectors mostly affected by climate change. Their yields are highly depending on the available amount of gaseous CO_2 in the atmosphere and its indirect influences on seasonal temperature, water supply, vegetation period, vermin and diseases (Chmielewski 2007). Advantages as well as disadvantages due to these described changes can be found for German regions. For example, today large parts of the country have good climate conditions for agriculture. Constraints for Northern Germany and the low mountain ranges are lower average temperatures, wetness and shorter vegetation period compared to the rest of the country and for Eastern Germany water shortages in major parts of the region. Therefore the first mentioned areas could potentially profit from climate change. In contrast regions with already appearing water shortages would be further stressed by climate change. In the following the impacts are considered isolated to accomplish a better overview.

Vegetation period

Due to the higher temperatures, the vegetation period will be expanded and the annual life cycle of plants will begin earlier. Rhineland-Palatinate and the Upper Rhine rift are the warmest regions in spring and therefore have already had a winning margin in blooming of fruit trees (Obstbau 2008). Today the average vegetation period in Germany accounts 235 days (air temperature ≥ 5 °C). Extension of vegetation period averages 25 days comparing 1961 with 2005 and further increases can be expected. For the REMO A2 scenario (version 2006) Chmielewski (2007) calculated an increase of vegetation period by up to 100 days until 2100; with highest increases near to the coast. Therefore agriculture and forestry in Schleswig-Holstein and Mecklenburg-Vorpommern, but also in parts of Rhineland-Palatinate, Lower Saxony and Brandenburg could profit with higher yields. Despite a prolonged vegetation period late frost in spring could damage higher developed plants.

CO_2 fertilisation effect

The CO_2 concentration in the atmosphere already increased from 280 to 380 ppm since the beginning of industrialisation. Laboratory experiments under optimal conditions showed an increase in yields due to the so called CO_2 fertilisation effect. As organic matter is basically composed of carbon structures, an increase of carbon availability can potentially lead to incremental growth rates. Most plants can be classified as C3- and C4- types based on the way they assimilate carbon dioxide into their systems. C4-plants like maize, sorghum and sugarcane will however not be significantly positively influenced (absorption potential of CO_2 is already saturated). C3-plants like root crops, rice, wheat, soya beans and most trees (95% of plants) on the other hand do profit in productivity from further increases in CO_2 concentration (Chmielewski 2007/Kleppler 2002).

Temperatures above the optimum, shortages in water and in nitrate supply reduce a positive CO_2 fertilisation effect. An optimal nitrate supply could be potentially constrained in

Germany by limitation in fertilisation because of climate and water protection reasons or too high financial burdens for the farms (Wechsung et al. 2008). In general, forestry can benefit more from the CO_2 fertilisation effect than agriculture.

Temperature range and water supply, extreme weather events

All plants have a temperature and water supply range at which yields are optimal. Wheat revenues e.g. are optimal at a lower temperature level than maize and an even lower level than fruits (Mendelsohn 2000). Winter wheat revenues could potentially decrease in Germany, as the period of ripeness of the grain is shorter with higher temperature (Chmielewski 2007). The common oak favours higher temperatures than common beech trees and even higher temperatures than spruces (Wagner 2004). Therefore the choice of species in agriculture as well as forestry will change with an increase in temperature.

The record-temperature summer of 2003 showed for instance the consequences of droughts on agriculture and forestry in Germany. Crop yields were around 12% below the perennial averages. Regionally, the impacts were heterogeneously spread. In Brandenburg, crop yields declined by 40%. Schleswig-Holstein could even take an advantage with a 7.9% gain in yields (UBA 2005). Also forests suffered seriously. With higher temperatures and water supply shortages the risk of fires, particularly forest fires rise, which is obviously a profound economic threat.

The fundamental risks leading to yield loss in agriculture are the increasing unpredictability of the weather and the more frequent extreme weather events (see section 4.4.2). The adaptation to unforeseeable extreme weather events is difficult, in contrast to gradual changes in the average temperature and precipitation. But the potential damages of these events are high; a single incidence of hail or strong precipitation can wreak massive economic losses. Extreme weather will occur more often only by the shift of the probability distribution of average temperature and precipitation (even at constant variance). So the forecast of yields will be more uncertain.

Vermin and plant diseases

Vermin and plant diseases could advance and spread with increase in temperature. In winter, vermin populations have better conditions to survive and the prolongation of the vegetation period leads to more progenies. Moreover after stress situations for the trees, particularly extreme weather events, vermin populations spread stronger because trees are weaker. For example the high share of spruce trees in German woods is highly stressed by the bark-beetle, which leads already today to huge economical losses (UBA 2005).

Another example is the "blue tongue disease", which is carried by insects and affects ruminants. In 2006 the virus was detected for the first time in Germany and since then wintered successfully for three times in middle Europe (data from March 2009). There are two different serotypes in Germany, but serums are available only for one of them (Mellor and Wittmann 2002, Gould et al. 2006, FLI 2009).

4.5.2.3. Vulnerability and adaptation

Prolongation of vegetation period, CO_2-increase and moderate temperature increase will benefit the plant growing. The yields stress factors in Germany's agriculture and forestry are expected to be shortages in water supply during summer (mainly in Eastern Germany), temperature increases above the optimal level of the plants (particularly in the Upper Rhine rift) and therefore higher risk of forest fires. Moreover, increases in vermin, diseases and extreme weather events will potentially lower revenues.

Currently the vulnerability for the agricultural sector is high for Eastern Germany (North-East German lowland, South-Eastern basin and hills). The coast zone, the North-West German lowland, the central low mountain ranges and the German Alps are classified as low vulnerable. The residual regions are classified as moderately vulnerable (UBA 2005).

The forestry sector is generally more vulnerable compared with the agricultural sector, as already today trees take longer to recover from extreme weather events because of longer rotation time periods. Spruces, making the major share of forestry area in Germany, are the trees mostly at risk, as they require wet and cool areas to grow, but are already now cultivated in unsuitable areas in Germany. Moreover, spruces have flat growing roots. Fir trees and larches also favour cool and wet regions. Beech trees can slightly better handle temperature increases. Oak, hornbeam and linden are regarded as alternative options (Kölling 2007). The Upper Rhine rift has already today an above average temperature and is therefore classified as highly vulnerable concerning forestry. Eastern Germany is also classified as highly vulnerable. The coastline and the North-West German lowland are classified as regions with low vulnerability and the residual regions as moderately vulnerable.

Exemplary studies on German agriculture

A study by Lang (2006) analyses the importance of climate conditions on agricultural land prices, where only West Germany is considered. Temperature, precipitation and some soil variables were taken as relevant control factors for the land prices. Land prices are assumed to be a proxy for the productivity of farm land. Furthermore, farmers are implicitly assumed to have experience about climate impacts on yields and to act rationally with regard to their farm land purchases. Then one can expect they are willing to spend more on farm land with favourable climatic conditions. The difference in land prices is the shadow price of the analysed climate variables. By using this hedonic approach physical and biological processes are completely left out of the picture; one rather measures the economic impacts quite directly by comparing different prices of different climatic situations. By nature, this approach is not feasible for measuring adaptation costs, since the farmer is already assumed to act optimally (which may or may not include adaptation). Thus, the shadow price must be interpreted as the impact of climate change after an optimal behaviour of the farmers. The concrete data to feed the model has been taken from the German ministry of agriculture, which has supplied a representative dataset from over 8,000 farms all across Germany. The model results suggest that West-German farmers are winners of the climate change in the short run because of increasing land values (highest land values can be achieved at a warming of +0.6°C). Most areas in Western Germany are estimated to be positively affected, mainly in the northern and middle part. The Pre-Alps do not benefit at all or just little. In the long run, losses from global warming may occur, if temperatures increase by more than 1°C.

Ashenfelter and Storchmann (2006) also used a hedonic model to estimate the change in cultivation possibilities for only one specialised crop type, namely wine. In comparison to the latter presented model, which delivered qualitative results, Ashenfelter and Storchmann go in for the calculation of quantitative results. They estimated the relationship between assimilated energy by the Mosel valley vineyards and the change in the prices of the vineyards. The vineyards of the Mosel region are located at 49.61° to 50.34° latitude, and therefore at the northern border of the commercial viticultural zone.

The presented model acts on the assumption, that vineyard quality and therefore land prices mainly depend on the available amount of solar radiation (another minor factor is soil quality, which is to some extent also being considered). Data records with a rating of land values have been studied for the Mosel region. The according amount of incoming solar energy has been calculated for single areas, using basic equations from solar and environmental physics. Following this way different amounts of incoming radiation energy could be connected to different land price values.

The results show that vineyard quality and therefore prices increase exponentially. An increase in temperature by 1°C would increase land prices by 20%, while a 3°C increase would more than double the value of the vineyards (Ashenfelter / Storchmann 2006). The estimation identifies a potential advantage for vine production. Although the study identifies positive impacts on winegrowing, these positive results can be only transferred to a small range of specialised thermophile crops. As the area vine cultivation has only a share of 1% of Germany's agricultural area, the detected advantages benefit only a marginal share of agriculture. Furthermore, both studies just feature a cut-out of the impacts on agriculture to come alongside with global change. For example the increase in extreme weather events or diseases and vermin are omitted in both studies and for the vine study additionally no impact of water shortage is considered. Both discussed studies do not clarify whether the achieved utility is expressed as gross or net value.

As mentioned above, Eastern Germany is already today under considerable restraints because of water shortages. Therefore the impact on Eastern German agriculture shall be regarded more specifically. Wechsung et al. (2008) quantified the changes in yield revenues until 2050[13], omitting adaptation measures. Precipitation, temperature and the CO_2 fertilisation effect were considered. Changes in extreme weather events, diseases and vermin were not implemented into the model. Ignoring the CO_2 fertilisation effect, the winter wheat revenues could explicitly decline in Brandenburg and Saxony and maize revenues all over Eastern Germany. Implying the CO_2 effect, winter wheat would slightly increase in crop yields and the decline in maize revenues in the North-Eastern lowland would be moderate. As mentioned above, the CO_2 effect is not precisely declarable, as its size depends on the overall supply with nutrients, water and the temperature. Mecklenburg-Vorpommern and Saxony-Anhalt would have revenue gains in winter wheat even without the CO_2 effect. The study suggests comprehensive cultivation of winter crops and short rotation plantations with fast-growing aspen trees as a measure of adaptation for the higher affected locations with sandy, poor soils and low water reservation.

For the state Hesse a rough estimate of the adaptation costs in the fruit-growing sector was carried out, considering provision and operation costs[14]. The main elements of expenditure were irrigation systems (also for frost protection) and nets for hail protection. Including all risks and weather effects to Hessian fruit cultivation areas, the annual additional costs for the sector would account 7.5 million € (HLUG 2005).

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[13] The study uses the STAR II model (based on the MPI global model). Temperature is estimated to increase on average by up to 2.7°C for Eastern Germany (higher than the REMO estimation) and precipitation to decrease in summer with higher declines for the North-East lowland and the South-Eastern basin and hills.

[14] The estimation is based on climate records of the 'Deutscher Wetterdienst' from 1951 to 2004 and simulated climate change time series until 2050 for the scenario B2.

A form of private reaction to a shift of temperature and precipitation conditions is the initiating of cultivation of thermophile plants like maize and soya. Another alternative would be the intensified cultivation of fruit trees. However, fruit trees have longer rotation time and returns cannot be realised before 3 to 6 years after the initial investments (Chmielewski et al 2007).

Management measures towards the growing of mixed forests and suitable species are already held in Baden-Württemberg and Bavaria to increase the resistance against vermin and climate change. Especially needful areas for further adaption were have already been classified in Bavaria. The adaptation enhances the share of deciduous trees in state woods, particularly beech (Kölling/Ammer 2006).

Wechsung et al. (2008) conclude in their study that the tendency of demand increases on markets for raw material and biomass production of farming land and supply restrictions could influence the market price positively, which could even over-compensate declines in yields.

Without adaptation measures Kemfert (2007) calculates possible damage costs of 3 billion € until 2050, applying the controversial WIAGEM model (Roson and Tol 2006).[15] The adaptation costs between 2026 and 2050 are estimated at 2.9 billion €. Regarding the fiscal effect of these adaptation activities, global estimations by IMF (2008) predict that only about 15% of all adaptation costs in agriculture, forestry and fishery are public costs. For lack of specific information about Germany we assume the predicted global estimations for Germany. This leads to public adaptation expenditure in the amount of about 0.44 billion € between 2026 and 2050. For forestry, there are no explicit adaptation cost data available, but the ownership structure (54% of forests are publicly owned) implies a high share of fiscal costs.

Proactive adaptation measures as presented in Table 5 are suitable to reduce these initial damages considerably. However, there will be regional and incidental residual damages like yield losses after unpredictable extreme weather events or forest fires which can be mitigated by e.g. insurance or risk diversification.

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[15] Kemfert (2007) is one of very few available analyses providing quantitative estimates of economic impacts and adaptation costs for total Germany. That is why this case study is citing this particular source several times. However, the limitations of this study, elaborated in section 2.1, p. 13 are still existent. The numbers provided by Kemfert (2007) have therefore to be taken with caution. Impact cost estimates are possibly too high, as adaptation effects are neglected, and also adaptation cost estimates come with a high degree of uncertainty. However, as long as other quantitative analyses are missing, we will have to draw on this source several times.

Table 5: Autonomous and planned adaptation measures in agriculture and forestry.

Impact	Adaptation measure	Autonomous		Planned	Nature of adaptation	
		Consumer	Producer	Public	Proactive	Reactive
Agriculture						
Increase in temperature	Change in cultivation to more thermophile plants (e.g. wine)		X		X	X
Increase in extreme weather events	Use of insurance		X		X	
	Floods: evaluating water protection guidelines			X	X	
	Droughts: cultivation of more drought resistant breeds		X		X	X
	Droughts: Irrigation systems		X		X	X
	Redesigning drainage systems		X		X	X
Earlier starting of vegetation period and elongation	Earlier seeding, potentially an additional crop rotation		X			X
	Expanding variety of crops and plants		X		X	X
	Developing of new crop types		X		X	
General impacts	Rearing more resistant crop types		X	X	X	
	Research on regional climate change			X	X	
	Increased use of fertilisation and plant protection (neg. externalities)		X		X	X
	Development of plant and animal disease and pest monitoring			X	X	
	Water-saving cultivation		X	X	X	X
	Considering new insurance regulation			X	X	
Forestry						
Pests	Earlier evacuation of trees after damage		X	X		X
	Control of pests and diseases			X	X	
	Enhance resistance of forest by mixed stands		X		X	
Forest fires	Rethinking of precaution measures (not concretised)		X	X	X	
	Developing monitoring systems		X	X	X	
	Defining fire breaks in forest management		X		X	

Change of favourable conditions for certain tree species	Cultivation of more productive tree populations		X		X	
	Use of alternative genotypes to prepare for different future scenarios		X		X	
General impacts	Forest transformation to higher diversification of tree types		X	X	X	
	Financial support for private owners			X		X
	Reconsidering the cultivation of foreign thermophile species		X	X	X	
	Developing of higher resolution climate change models suitable for regional projection			X	X	
	Research and development of new harvesting techniques and tree improvement		X	X	X	
	Field mapping and regional cultivation recommendation			X	X	
	Rearing more resistant tree types		X	X	X	
	Knowledge transfer of experts			X	X	
	Evaluation of current water management concepts			X	X	

4.5.3. Tourism

4.5.3.1. Basic outline

In 2004, 8.9% of National GDP was directly or indirectly originating from tourism (Statistisches Bundesamt 2006). Moreover, 2.8 million employees are working in the tourist sector. Therefore it is one of the important economic sectors for Germany.

Currently, the regional distribution of internal tourism is spread relatively equally. In contrast, international tourism mainly concentrates in south and south-west Germany. Upper Bavaria has the highest market share with 13.5% of domestic tourists and 7.9% of international tourists (Hamilton et al. 2006).

Winter sports tourism (e.g. Ski alpine, cross-country skiing) and some forms of summer tourism (e.g. beach vacations, hiking) are particularly dependent on climate and weather conditions. Winter sport tourism only accounts for 3% of all holiday trips with overnight stays in Germany. Similar gross revenues originate from winter day trips (UBA 2005).

Non-seasonal city, culture and health tourism is less dependent on weather change (Matzarakis and Tinz 2008). This chapter therefore focuses on the winter and summer seasons, since winter tourism is expected to suffer, while summer tourism is expected to stay equal or to profit slightly.

4.5.3.2. Climate change impacts on tourism

Winter sports tourism

The revenues due to winter sports tourism may seem low, but winter tourism is highly concentrated in the German Alps and the low mountain ranges. Therefore climate change and with it the reduction in snow cover can have strong regional economic consequences. UBA (2005) refers to a case study undertaken for the Fichtelgebirge, a low mountain range in the North-East of Bavaria. Results show that only one out of six ski resorts would have sufficient snow cover by 2060 assuming a temperature rise by 0.4 degrees per decade. According to studies conducted in Switzerland, only Alpine ski resorts above 1,500 m a.s.l. and low mountain rages above 800-1,000 m a.s.l. would have sufficient snow cover, when assuming an increase of mean annual temperature by 2°C (UBA 2005). The snow line is estimated to recede by 150 m altitude difference due to a 1°C increase in air temperature (World Tourism Organisation 2003). The maximal altitude of the low mountain ranges reaches approximately 1,400 m. The German Alps have a maximal altitude of 3000m, but it mostly reaches 1,200 to 2,000 m (Zahn et al. 1996). In Baden-Württemberg the dominant altitude of mountains lies between 300 m and 700 m a.s.l., and only 1.4% of the territory lies above 1,000 m. Thereby the North and South Black Forest includes most of high altitude areas. The Swabian Mountains are particularly appropriate for artificial snowmaking with more than 24 days of potential use of snowmaking technology. This amount is expected to decrease significantly; a study assesses that already by 2025 possibilities of snowmaking for at least 18 days will occur only above 1,000 m a.s.l. in the South Black Forest (currently boasting the highest concentration of lifts) and above 900 m in the Swabian Mountains. (Deutsche Sporthochschule Köln 2005).

The skiing season is expected to shorten significantly by 2050, which would result in lower revenues. On the other hand, increased precipitation is expected in winter months, which could result in an increase of the amount of snow at higher altitudes. A study based on REMO 2006 (scenario A1B) estimates that the skiing season will be 9 days shorter (approx. 27% change) on the Feldberg in the Black Forest (low mountain range) and 10 days shorter (approx. 5% change) on the Zugspitze (German Alps) (Matzarakis / Tinz 2008). Abegg et al. (2007) assesses Germany to be the most endangered Alpine country. Under present conditions, 47% of the ski areas in Swabia are naturally snow-reliable, and 90% in Upper Bavaria. A rise in temperature by 1°C would lead to a decrease in number of snow reliable ski resorts by 60% in the German Alps (Swabia being more affected than Bavaria); a 2°C-increase would reduce the number of ski resorts by 13% with small differences between the sub-regions[16]. Further consequences to be mentioned are the increased risk to the technical infrastructure (e.g. ski lifts) as a consequence of melting glaciers and thinning of permafrost soils.

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[16] Switzerland as a comparison: increase in 1°C would lead to 10% loss, increase in 4°C to a 50% loss

Summer tourism

As climate change has a stronger impact on Southern Europe, a drop in tourism has to be expected during the summer season for these travel destinations. Northern European regions, and therefore Germany, could benefit from this development in international summer tourism as rising temperatures and less precipitation are expected for the summer months (World Tourism Organisation 2003). Also the project ‘coastal tourism and climate change’ carried by the Institute for Tourism and Recreational Research in Northern Europe (Institut für Tourismus und Bäderforschung in Nordeuropa) shows a slightly positive development at the North and Baltic Seas until 2030, if a slow warming takes place (Rau 2008).

Furthermore, the above mentioned study of Matzarakis and Tinz comes to the conclusion that the number of days per year with thermal comfort[17] would increase by 4 days in Husum (North Sea) and by 10 days in Rügen (Baltic Sea). Precipitation would decrease in the Northern and Baltic Sea region. The bathing season currently lasts from middle of June to end of August. By 2050, it is estimated that the bathing season will increase by 25 days. Thermal conditions are expected to improve and therefore the touristic potential is likely to increase, particularly on the Baltic Sea (Matzarakis and Tinz 2008).

A model estimating the impact of climate change on tourism in Germany comes to the conclusion that climate change will increase the number of domestic holidays by up to 15% by 2050. The model results show that domestic tourists as well as international tourists will slightly increase their travelling to the South-East of Germany. In addition, touristic flows would increase in the North-East according to the B1 scenario, and in the South-West according to the A1 scenario. Changes are however small. The higher gain in South-Germany can be explained by higher current climatic attractiveness and the further higher attractiveness increase due to faster temperature increase compared to the North. Therefore Germany is not reflecting the general tourism shift to the North, but a shift to the South-East (Hamilton 2006).

4.5.3.3. Vulnerability and adaptation

Winter sports tourism

As discussed above, the highly vulnerable regions for winter tourism include all the German mountainous regions where winter sports are offered, especially since a relocation of ski resorts in higher altitudes is highly restricted in Germany. Even the Bavarian Alps (1,050 to 1,200 m) (OECD 2007b) are relatively low compared to other Alpine regions. Moreover, most resorts in Germany are small and offer few options of conglomeration to improve the economic situation. Other behavioural adaptation measures are changes in operation practices, financial support and winter sports diversification (e.g. winter hiking). Examples of technical measures are shifts of ski resorts to higher altitudes or the north faces of the slopes, landscaping and slope development (for reduced snow depth requirement - in Bavaria 27% of skiable domain have been modified by these measures) and artificial snowmaking. The latter option is a currently widespread and increasingly used adaptation measure. In 2008/2009, 13% of Bavarian skiable slopes was covered by artificial snow. During the period of 2000 to

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[17] Matzarakis and Tinz (2008) define thermal comfort or “thermal adequacy” by a separately calculated temperature factor called “physiological equivalent temperature (PET)”. The PET is calculated by air temperature, wind speed, vapor pressure and thereby humidity, and average radiation temperature. Thermal comfort is assumed when the PET is between 18°C and 29°C.

2004, the amount of artificial snow increased from 323 hectares to 425 hectares (Abegg et al. 2007) and to 480 hectares in 2008/2009.

Along with the expansion of areas with artificial snow in Germany, state legislation became more and more conducive. Since 2004, the state parliament has relaxed restrictions on the operation of snowmaking equipment, leading to an almost 20% increase in slopes depending primarily on artificial snow (Knauer 2007). In 2009, the Bavarian state parliament passed a regulation on financial support for artificial snowmaking facilities, which allows state level subsidies for those facilities which are not eligible for EU subsidies. The bill does not mention concrete means or subsidy amounts. The bill however refers to EU subsidies in the amount of 10-20 % of total investments for cablecars, hence one may assume subsidies in the same order of magnitude for snowmaking facilities, due to a lack of alternative information.

Considering long term climate change, artificial snowmaking could be an option in the short and middle term for resorts in high altitudes; in the long run this option would be unsuitable for Germany as temperature has to be less than -2°C to be profitable (Abegg et al. 2007). UBA (2005) even names -4°C as the critical mark for the majority of snow cannons to be profitable. The installation of artificial snowmaking systems amounts to circa 25,000 to 100,000 € per hectare and the production costs of one m^3 of snow sum up to between 1 and 5 Euros (Deutsche Sportschule Köln 2005). Another study calculates the costs at 3 to 5 Euros (CIPRA 2004). In addition to this, costs of energy (amounting to 46% of the costs in France) and water supply[18] need to be considered. Moreover costs of snowmaking increase disproportionally with warming. Therefore investments should be well planned. In Baden-Württemberg, the longest profitable investments can be expected for higher altitudes in the South Black Forest and the Swabian Mountains (Deutsche Sportschule Köln 2005). Most ski resorts in Germany do not have the dimension for such investments to be profitable (UBA 2005, Abegg et al. 2007). Germany in comparison to e.g. Austria has no explicit regulations concerning snowmaking; the only applicable legislation concerns water regulations.

Adaptation of winter tourism must be carried out locally as weather conditions can strongly vary. Moreover, extensions of insurance are challenging as finding enough actors with negatively correlated risks to the same weather index is difficult. Public financial support is expected to rise further, as a growing number of operators consider snowmaking to be a 'public service' (Abegg et al. 2007). The current legislative development in Bavaria mentioned above is broadly in line with these expectations.

Summer tourism

Despite the expected rising of temperature comfort particularly on the coast, and the higher (international) tourist flows due to warmer climate, there are also some threats to summer tourism in Germany that need to be faced. Summer tourism on the German coast could be negatively influenced by extreme weather events, lower quality of ecosystems and sea-level rise. As tourism is highly volatile, these impacts could lead people (mainly elderly people affected by high temperatures) to stay home. Moreover, the low seasons (spring, autumn) in Southern Europe would probably stay or even gain in attractiveness because of more advantageous conditions and thus will remain a competitive alternative to holiday in Germany (IPCC 2007). Furthermore rising sea levels in German coastal regions will also affect tourism

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[18] Beside these direct costs, externalities (e.g. on landscape, biodiversity and water balance) should also be considered.

in this area or alternatively lead to high investments. Therefore, summer tourism in Germany is overall classified as moderately vulnerable by UBA (2005). If warming is slow and adaptation measures are met, the tourism sector could even profit (UBA 2005, Rau 2008). The research centre GKSS interviewed 60 tourism stakeholders on the supply side in North Germany (Schleswig-Holstein, Hamburg, Lower Saxony and Mecklenburg-Vorpommern). More than a half of the interviewed persons regard climate change as an important topic for tourism in North Germany. But scientific results are little known by the respondents and just a minority has knowledge about adaptation measures. This explains the results of the UBA (2005) study that little autonomous adaptation is observable at present (Rau 2008).

Comprehensive identification of vulnerability and adaptation

For a comprehensive identification of vulnerability and hence adaptation measures, the socio-economic dimensions of tourism have to be considered on the national (e.g. economic and demographic development) and international scale (e.g. risks linked to conflicts, natural hazards and fear of diseases). A number of papers identify a considerable economical impact of climate change on tourism (Berrittella et al. 2006, European Travel Commission 2006). However, the knowledge base on impacts caused by climate change is not yet sufficient for defining specific adaptation measures for tourism in Germany (UBA 2005). Kemfert (2007) calculates the whole climate change damages costs on tourism to be up to 19 billion € and the costs of adaptation are estimated to amount to 11 billion € for the next fifty years, assuming a temperature increase of 4.5°C by 2100. In contrast to the issue of tourism as a cause of environmental damage, adaptation to climate change is still hardly faced by the German tourism industry (UBA 2005, Rau 2008).

The tourism sector in Germany should be able to implement the needed adaptation measures (Rau 2008, UBA 2005). Alternatives that have already been identified could be hiking and mountain climbing as days of thermal comfort will increase over the years (Matzarakis 2008). A more intensive development of leisure activities and travel that offers independence of climate conditions is also widely recommended in Germany (Rau 2008, Deutsche Sporthochschule Köln 2005). Furthermore, winter tourism operators are advised to expand the use of existing infrastructure for other seasons to increase cash flows (e.g. the use of ski lifts for mountain bikes) (Deutsche Sporthochschule Köln 2006). In contrast, the investment costs of maintaining basic ‘natural’ resources of tourism like artificial snow and extension of dikes have to be well considered as uncertainty is high.

The tourism industry is largely individualistic. However, laissez-faire may not prove to be efficient as externalities, e.g. repercussions on water supply due to using more water for snowmaking, have to be regulated for environmental protection reasons. There is also considerable pressure on local and regional authorities to support private adaptation measures since tourism in many cases is essential for the economy of local communities and regions. Moreover, the federal government supports the project KUNTIKUM (translated: Climate Trends and Sustainable Development of Tourism in Coastal and Low Mountain Range Regions). In this project, new tourist products and infrastructure shall be developed in collaboration with climate scientists and financed with public funding

Table 6: Autonomous and planned adaptation measures in the tourism sector.

Impact	Adaptation measure	Autonomous		Planned	Nature of adaptation	
		Consumer	Producer	Public	Proactive	Reactive
Winter sport tourism						
less snow reliability (particularly in low altitudes)	Technical measurements (particularly artificial snowmaking)		X	X*)		X
	Reconsidering of legislation			X	X	
	Concentration of slopes in higher altitudes (constrained)		X		X	X
	Visit higher altitude winter resorts	X				X
Summer tourism						
Increased occurrence of algal blooms	Control of bathing quality			X	X	
Sea-level rise at touristic sites	See section 4.5.1		X	X	X	X
Increased potential for summer tourism (particularly beach holidays)	Enlargement of the touristic offer		X		X	X
Total tourism sector						
General impacts	Changing in recreation and travel behaviour	X			X	X
	Increase of weather independent offers		X		X	X
	Diversification of tourism industry (e.g. alpine tourism)		X		X	X
	Provision of information about regional features		X**)	X	X	X
	Expansion of current research			X	X	

*) In case of public subsidies for artificial snowmaking; **) Touristic companies may form alliances to cooperate in regional and local marketing.

4.5.4. Human health

4.5.4.1. Basic outline

Germany's health care system is in good condition, compared to other countries, as its financial, human and physical capacities are on a high level. In 2007, the expenditures on health made 10.4% of GDP - the highest expenditure after USA, France and Switzerland. In health spending per capita, Germany is on the 10th position of the OECD countries. 76.9% of health spending was funded by public sources (OECD 2009). In 2002, 87% of the population were ensured by a statutory health insurance. The remaining population was mainly privately insured and only 0.2% had no insurance at all (WHO 2004). Partly due to cost-containment measures that have been introduced in the context of health system reforms, spending per capita increased in real terms less than one third compared to the OECD average between 2000 and 2005. Moreover, the containment of health spending growth is expected to persist because of further health care reforms (OECD 2007a).

The highest vulnerable group for further health risks comprises children and elderly people as human adaptation capacity decreases with age. Currently the number of people over 65 years accounts approx. 16 million. Until 2050 an increase of 23.5 to 24.7 million people over 65 years is estimated, increasing the share in total population of 30% to 36% (Statistisches Bundesamt 2006). Besides, children are highly vulnerable to health threats.

4.5.4.2. Climate change impacts on human health

Direct impacts on human health

Direct effects on human health result from extreme weather events such as floods, storms, heat stress during summer and cold stress during winter. The cold stress situation for Germany can be expected to improve as winter will become warmer. It is estimated that the increase in summer mortality is much higher than the decrease in winter mortality due to higher temperatures (Hübler et al. 2008, Jendritzky 2007). Thus, heat stress is the most important direct negative impact on human health in Germany. Beside life losses and further financial burdens to the health system, well-being and productivity are potentially impaired. Hübler et al. (2008) roughly monetised Germany's direct climate induced health risks for the period 2071-2100. The estimation shows that the annual hospitalisation costs will account for approx. 300 to 700 million € in today's prices. This would make an averaged 6-fold cost increase of the current hospitalisation costs. Spending on ambulant treatment is not included here. The losses in labour productivity are significantly higher. The study suggests a reduction of productivity of 3 to 12%. The estimation assesses therewith losses of 0.1 to 0.5% in Germany's GDP; 4 times more than today's losses due to climate impacts (Hübler et al. 2008). However, adaptation measures are fully neglected in the study.

Indirect impacts on human health

Water shortages can affect the availability of clean drinking water and the efficiency of wastewater treatment and therefore cause an increase in diseases. Another negative impact on water can be the impairment of drinking water by the occurrence of algal blooms in German rivers and lakes and their excretion of toxic substances. Shortage of water and toxication through algal blooms already appeared during the 2003 heat wave in Germany.

The increasing concentration of allergens could further put pressure on human health. As stated above, the vegetation period in Germany will shift and elongate due to climate change, therefore also the allergen season. Also the impact on the quality of food is discussed. For example the appearance of the temperature sensitive salmonellosis could increase. But as professional storage and distribution can prevent this impact, this danger seems to be low for Germany.

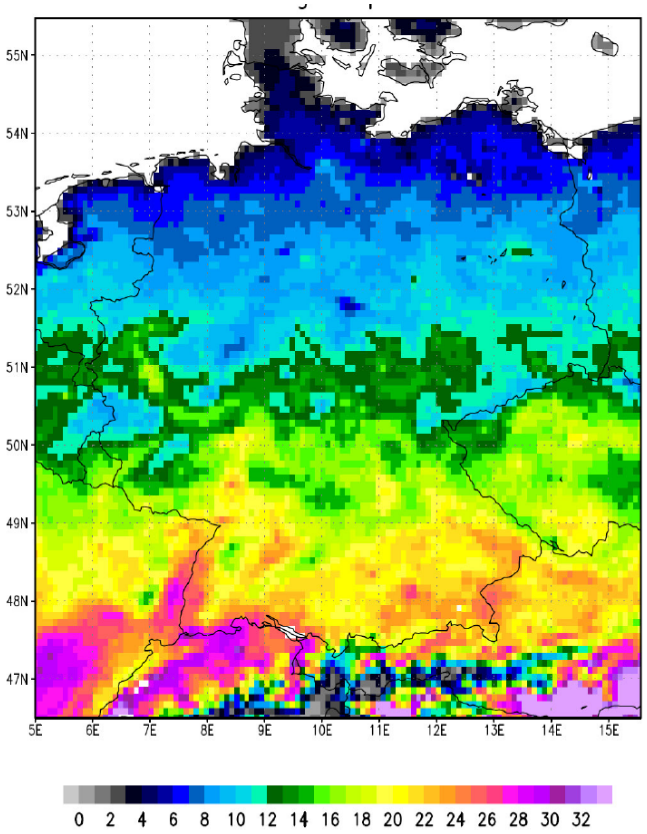
Vector-borne diseases are the most threatening indirect impact on human health in Germany. Studies undertaken in Sweden and the Czech Republic come to the conclusion that Lyme borreliosis and tickborne-encephalitis have already spread into higher latitudes and altitudes (UBA 2005). Therefore this development can also be expected for Germany. Beyond, also other vector-borne diseases are considered to appear in Germany, e.g. malaria. Malaria occurred until the 1950s in Germany. But a recurrence is discussed controversially.

4.5.4.3. Vulnerability and adaptation

The Upper Rhine and congested urban centres (particularly in closed valleys) are already today under considerable strain due to above-average temperatures. Heat stress is higher in congested urban centres relative to their surrounding areas because of reduced airflow and therefore less cooling. Furthermore, less cooling-down by night, important for periodic recovery, occurs for urban centres. In Germany, nearly 90% of population lives in urban centres (WHO 2004). Highly vulnerable zones are the West German lowland bay, the South-Eastern basin and hills, and particularly the Upper Rhine Rift. Lower vulnerability occurs for the coastal zone, the North-West German lowland and the Alps. The remaining zones in Germany are classified as moderately vulnerable to heat stress (UBA 2005).

Figure 17 gives an overview of the predicted increase of heat days in Germany. The effect of urban development is recognisable in the greater heat in Hamburg and Berlin compared to the environs. The vulnerability to heat waves will increase accounting for the demographic development because the share of the over 60 year old people is increasing further.

Figure 17: Change in heat days, 2071/2100 compared to 1971/2000. Source: Hübler et al. 2007.



Today, proactive adaptation to climate change is hardly implemented in the health sector (UBA 2005). As an applied adaptation measure the German Meteorological Service (DWD) has implemented a heat-warning system, with a scaling to the level of administrative districts. Heat warnings are released if thresholds are exceeded. Additional adaptation options are the provision of information about prevention and therapies by public health authorities, as well as specific education of medical and nursing staff. Alongside, a further implementation of technical prevention measures (e.g. fresh air ventilation, insulation, cooling systems), local emergency planning and the knowledge of city climate must be strengthened. (UBA 2005, Jendritzky 2007). Baden-Württemberg and Hesse have already implemented a high information supply on heat stress and prevention measures for private use. Adaptation measures to heat stress seem to have a high potential as a study for Milwaukee in the USA shows: due to adaptation measures a reduction of heat deaths by 49% was achieved during the period 1995 to 1999 (Hübler and Klepper 2007). However, still the remaining effects (residual damages) are considerable.

Autonomous adaptation measures were assessed by Kuttler (2009). While electricity spending generally drops when temperature increases, he documented for the city of Essen that consumption starts to increase again with exceeding of a certain temperature threshold. The explanation is the increased use of air conditioners.

Concerning vector-born diseases, by now adaptation measures hardly exist in Germany at present. The adaptation capacity is of small potential for most of the vector-borne diseases as no immunisation measurements are tangible yet. Just long term therapy with marginal success is available. The reduction of information asymmetries and provision measures as well as the connection to climate change should be further tracked (UBA 2005).

Vulnerability for vector-borne diseases throughout Germany is regarded as moderate for Northern Germany (the coast, North-West German lowland and North-East German lowland) and the German Alps. The remaining zones are identified as highly vulnerable. But this valuation is aligned with high uncertainty of prediction because the connection between climate change and vector-borne diseases is still uncertain. Information on the interrelation with climate change must be enlarged as well as the lack of education and prevention measures should be faced. Warning and education are regarded as potential options, already applicable in the short run. If further adaptation measures are met, vulnerability should be reduced significantly (UBA 2005).

Concerning the costs of adaptation, Kemfert (2007) calculates the costs between 2026 and 2050 at 13.8 billion €. In Germany, around 73 % of the total health expenditures are borne by public funds. For lack of specific information on health adaptation costs we assume this to hold for adaptation measures, which would translate into public adaptation expenditures in the amount of about 10.1 billion € between 2026 and 2050.

Hübler et al. (2007) analyse several private and public adaptation options for Germany, such as acclimatization, behaviour modification, usage of health service, technical prevention measures (air conditioner), newsletters and early-warning systems. Climate change impacts on human health depend on the ability to adapt to high temperatures, so the study suggests that in the long run acclimatization is important. E.g., behaviour modifications in working life and free time due to climate change could reduce health risks. Behaviour modification causes no direct adaptation costs but could reduce the quality of life and thereby cause opportunity costs. An increasing use of health services is very important particularly for senior citizens as they need an intensive care during days with very high temperatures. In Germany there are several newsletters and early-warning systems to inform about impending danger of extreme climate events and about the correct reactions. Early-warning systems issue a warning when extreme weather events or moderate weather events for several days are predicted. In Baden-Württemberg and Hesse early-warning systems inform after two days of extreme high temperatures via internet, radio and telephone the doctors, hospitals and general public. Private adaptation options such as acclimatization, behaviour modification and some technical prevention measures (e.g. air conditioner) do not cause public expenditures. Newsletters about correct reaction to extreme weather events only cause low public expenditures, and early-warning systems cause moderate public expenditures. Intensive care of endangered persons during extreme weather events is very personnel-intensive, thus leading to high public adaptation costs in the public organised health care system. Building measures to adapt to climate change such as improvement of isolation and urban planning are very expensive and partly public investments. Table 7 summarises the impacts on human health and consequent adaptation measures.

Table 7: Autonomous and planned adaptation measures concerning human health.

Impact	Adaptation measure	Autonomous		Planned	Nature of adaptation	
		Consumer	Producer	Public	Proactive	Reactive
Heat stress	Dissemination of information about correct reaction to heat-waves			X	X	
	Development of early-warning systems for healthcare comprising regional particularities			X	X	
	Technical prevention measures (e.g. air ventilation, cooling, isolation)	X	X		X	X
Vector-borne diseases	Provision of information for the population and medical staff			X	X	
	Vaccination programs			X	X	
	Research and monitoring of climate change related diseases (particularly vector-borne)			X	X	
	Expansion of monitoring systems			X	X	
General impacts	Behavior modification in working life and leisure time	X				X
	Adaptation in urban planning (green-fields)			X	X	
	Increasing use of health service	X				X
	Enlarging health sector capacity			X	X	
	Enlargement of the knowledge base, particularly on city climate and diseases			X	X	

4.5.5. The energy sector

4.5.5.1. Basic outline

In Germany, 26% of power generation is based on nuclear power, 25% on brown coal, 22% on hard coal, 11% on natural gas and 10% on renewable energy. Since the mid 1990s the power generation by renewable energy strongly gained, particularly due to the wind energy plant increases (BMU and BMWi 2006). A major share in this continuing development has the implementation of the ‘Act on Granting Priority to Renewable Energy Sources’ in 2000. The primary energy consumption declined constantly during the last years, accounting 14,000

PJ in 2007[19]. In contrast, the consumption of electricity increased during the period 1990-2005 by 11%. But until 2020 a decrease of up to 5% is expected. Primary energy imports increased in the past and amount currently to 71% of the total primary energy consumption (BMWi 2008).

Due to the European legislation, electricity and gas markets are liberalised in Germany. Currently four system operators of power transmission are represented on the German market, namely RWE, E.ON, Vattenfall Europe and EnBW. Together they share 80% of the domestic power plant capacity. Besides, smaller regional suppliers and local public services exist in the market. For the German electricity supply a considerable amount of investment and modernisation is needed for the future. Until 2030 share of more than 50% of the existing power plant capacity will be replaced (BMU / BMWi 2006).

4.5.5.2. Climate change impacts on the energy sector

The public energy sector uses 56% of the total water supply for cooling purpose (UBA 2005). Particularly thermal power plants (e.g. coal-fired, natural gas and nuclear power plants) are dependent on sufficient water availability. Energy supply by thermal power plants is stressed by lacking water and higher water temperatures and therefore smaller cooling effect during summer. Climate change combined with requirements of water legislation could further worsen the situation. During the heat wave in 2003 shortages of production occurred; this led to special approvals of public authorities and some power plants were allowed to advance the influent temperature of used cooling water from 28 to 30°C (UBA 2008a). Higher influent temperature can thereby have considerable impacts on flora and fauna in river habitats.

In the past, supply in the summer was further stressed by the fact that less capacity of electricity generation was available due to maintenance work during summer. The purchase of electricity from abroad could smooth the situation (EnBW 2003a).

As mentioned in 4.5.4 Kuttler assessed that the use of air conditioners increases from a certain level of temperature. A press release by the energy company EnBW (2003) also underlies this effect of autonomous adaptation as it is stated that the electricity demand was above average due to the heat. Particularly in summer, impacts could be high as supply could decrease and demand could increase. On the other hand autonomous adaptation is also headed in the other direction. An appeal to reduce the electricity consumption decreased demand. During winter months, a decrease of heating energy demand can be expected as temperature rises. Independent of season, the energy infrastructure could be further stressed by more frequent extreme weather events, like droughts and heat waves.

Besides, even renewable energy sources could struggle under the new circumstances: for example the efficiency of run-of-river hydro plants could potentially be negatively influenced by low as well as high water and wind energy plants could be strained by increased storms. At the same time, the revenue functions of biomass utilisation could be positively influenced by climate change as these plants are mainly C_3 plants.

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[19] Deutschland in 2007: Wirtschaftswachstum rauf, Energieverbrauch runter (20.12.2007). www.bmwi.de, downloaded on 13.10.08.

4.5.5.3. Vulnerability and adaptation

As shown above, Germany’s energy sector will have to face multiple threats and opportunities due to climate change. No specific studies have been carried out to quantify the impacts, a specific valuation of net impacts in production, distribution and consumption cannot be given here. Further research is therefore needed.

As for energy consumption in winter, one autonomous adaptation measure is the saving of heating energy. Bräuer et al. (2009) calculate a total amount saved by climate change of 2.5 billion € p.a., only taking gas into account. Assuming a reasonable share of public heating expenses, this translates into public saving of 500 million € p.a.. The study estimates the total energy-related fiscal costs of climate change (including adaptation costs) at 5-7 billion € p.a., however by using questionable simplification methods due to a lack of appropriate data.

As for the adaptation in energy production, some German power plants will have to be replaced in the near future. Therefore it can be expected that adaptation measures will be considered in new plant planning. Table 8 gives an overview of impacts and potential adaptation measures in Germany. Residual damages highly depend on the extent of realised autonomous adaptation measures. If power suppliers do not clarify cooling alternatives in hot periods or do not look for alternative raw material transport possibilities, economic damages by extreme weather events may increase in the long run. It should be mentioned that producers here only bear parts of the losses that occur by eventual supply failures. Instead, large parts are borne by the consumers. If that is the case, one can assume inefficiencies since there is a lack of incentives for investing in “climate-proof” infrastructure and producers autonomously would under-adapt and residual damages may be larger than in the optimal case (Eisenack 2009). In the case of sufficient incentives for paying the premiums, private insurance can play an important role in mitigating and calculating the residual economic costs.

Table 8: Autonomous and planned adaptation measures in the energy sector

Impact	Adaptation measure	Autonomous		Planned	Nature of adaptation	
		Consumer	Producer	Public	Proactive	Reactive
Higher temperatures in winter	Decreased use of electricity for heating*	X				X
Higher temperatures in summer	Increased use of electricity for cooling*	X				X
Inland water transport unreliable	Risk diversification, less dependence on water ways.		X		X	
Limited water cooling capacity in summer	Research for alternative cooling-systems		X		X	
Improved temperature conditions for biomass	Expansion of use		X	X**		X
Extreme weather events	Extension of underground power cable		X		X	
Changes of wind velocity	Clarification of future changes in wind velocity			X	X	
	Adapt to changing wind velocity		X		X	
General impacts	Research expansion in alternative power generation		X	X	X	
	Provision of information how electricity needs can be reduced		X	X		X
	Increased investments		X		X	

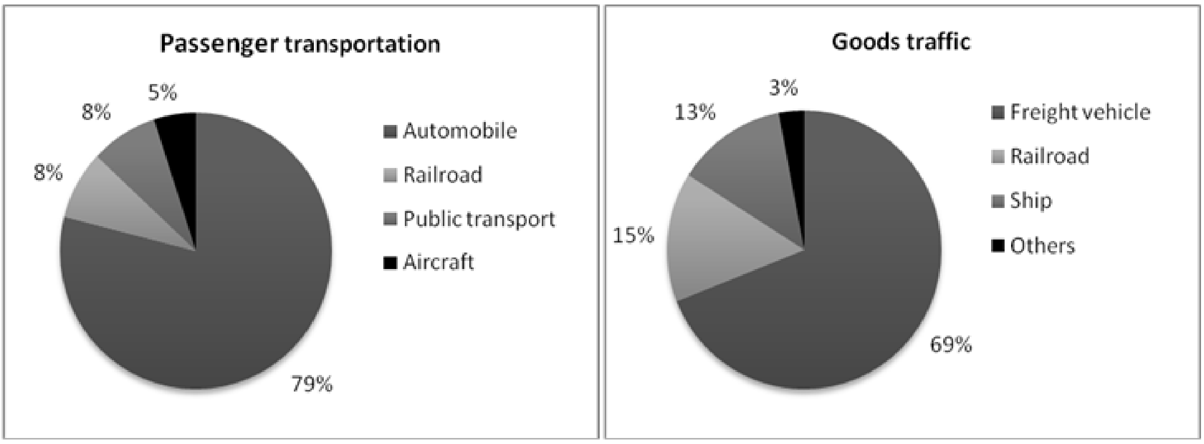
total effect is unclear; ** in case of subsidies for biomass energy.

4.5.6. *The transport sector*

4.5.6.1. Basic outline

The transport sector is split into passenger transportation and goods traffic. Means of traffic are air, road, rail traffic and shipping. Thereby the road traffic is dominant with a share of 79% in passenger transportation and 69% in goods traffic. Figure 18 shows the according distributions. The trans-regional road transport infrastructure accounts 231,400 km (www.destatis.de, Verkehrsmittelbestand und Infrastruktur).

Figure 18: Split of passenger traffic and goods traffic in Germany. Source: UBA 2005.



The data provided by Eurostat differ slightly from the splits of traffic means presented above, possibly due to different statistical concepts. However, the main picture (predominance of the road traffic in Germany in passenger as well as goods traffic) does not change. According to Eurostat, the modal split of freight transport in 2007 (in tons km) was 22 % per railway, 66 % per road and 12 % per inland waterways (Eurostat 2009b, p. 114).

4.5.6.2. Climate change impacts on the transport sector

Considered direct impacts are increases in the frequency of heat days and other extreme weather events like storms, hail and floods as well as decrease in frost and ice days. Increase in heat days during summer will have considerable negative impact on the road traffic safety as concentration of drivers is expected to decline due to physical stress on the one hand and as the quality of roads will suffer from higher temperatures on the other hand. Thereby, casualties in public traffic will probably increase. Arminger et al. (1995) have calculated for Germany that the amount of accidents rises by 22% for city traffic and 13% for non-city traffic if temperature exceeds 32°C. If temperature rises to even 37°C the increase accounts 33%.

Also the damages to the transport infrastructure (particularly to asphalt and bridges) will increase with warming. The quality of rail lines and airport runways will suffer from an increase in heat days too. Rail lines deformities, road and airport runway pavement damages and thermal expansion on bridge joints are expected due to an increase in heat days. Also flight cancellations and delays are expected due to limitations in take-off load limits at hot-weather airports with insufficient runway length. Furthermore engine overheating will be a problem for the whole transport sector (Transportation Research Board 2008).

Extreme weather events potentially will also lead to high costs to public authorities due to infrastructure damages. For example the number of overthrown trees by storms and scouring and slope failure at routes and rail lines by heavy rainfall events may increase. More frequent inundations of roads, rail lines and flooding of tunnels are expected due to a seasonal increase in precipitation. Also more frequent interruptions and delays in air traffic are expected due to an increase in extreme weather events like storms and hail. Water traffic will suffer from damages to harbour infrastructure like cranes, docks and terminal facilities.

Moreover, high economic costs can be expected if transport is delayed (UBA 2005). On the other hand, the whole transport sector can be expected to profit in winter as a decrease of frost and ice days will take place with warming and less expenditure is expected for ice and snow removal. Particularly water traffic will profit from extended shipping seasons in inland waterways due to reduced ice coverage. However, shipping will also be affected by high and low water levels. Particularly on the rivers Elbe, Rhine and Weser impacts will be large.

The highest impacts can be expected for the road infrastructure. The need of action for the inland water transport was surveyed by the Federal Ministry of Transport, Building and Urban Affairs with its administrative authorities.

4.5.6.3. Vulnerability and adaptation

Throughout Germany a moderate vulnerability of the transport sector to climate change is identified. Little research took place in the past for the transport sector as for the energy sector. The technical adaptation measures are numerous for the transport sector. For example heat resistant building materials and the relocation of roads and protective constructions can be adopted. For the example of overthrown trees, the legislation can be expected to be revised to simplify the permission to prune back the trees. Thereby it needs to be considered that many woods are privately owned in Germany. Adaptation measures for transport infrastructure can be expected to be cost-intensive. However, if adaptation is carried out, vulnerability is expected to be reduced to a low level, thus residual damages are moderate in the transport sector.

As an attempt of quantifying the public costs in transport infrastructure, Bräuer et al. (2009) use a benefit transfer method and applies results from a study for the UK and adjusts them for the German situation. According to the authors, climate damage costs in the transport infrastructure may amount to 400-500 million € p.a. in 2050 and 0.8-1.4 billion € p.a. in 2100, composed of costs for heat damages on roads and tracks, costs by floods, and savings by reduced winter service. Assuming that traffic infrastructure is predominantly public-owned and -maintained, these expenditures directly translate into public costs. Since these costs represent the total spending in the transport sector, the pure adaptation costs must be lower. Nevertheless, as the direct damage mainly accrues to the public budgets, the figure can serve as an upper limit of adaptation costs.

In contrast, Kemfert (2007) gives an estimate of explicit adaptation costs, however for the aggregate sector trade, commerce and transport. She estimates the costs at 18.2 billion € in the period 2026-2050 and 75.9 billion € in the period 2075-2100. Beside the fact that these costs accrue to different sectors, they are of public as well as private nature. But assuming that the largest impacts under the sectors are to be expected in the transport sector and that there is a significant share of public investment in that sector, one can deduce from Kemfert (2007) a fiscal burden of more than 40 billion € (which translates into 1.6 billion € p.a. at the end of the century), notwithstanding that the underlying calculation base on a controversial modelling approach and assumptions (Roson and Tol 2006).

In road traffic the development and use of new heat-resistant pavement material is one measure to adapt to an increase in heat days. Adaptation options to an increase in extreme weather events like storms, hail and flooding are the upgrade of drainage systems and increases in the pumping capacity of tunnels. Protection measures like elevation of streets, bridges and buildings and strengthening or heightening of levees, seawalls and dikes may also become necessary to adapt to an increased risk of flooding.

Regarding rail traffic, a greater use of continuous welded rail lines will be necessary to adapt to an increase in heat days. Adaptation options to an increase in extreme weather events are changes in bridge design, increases in pumping capacity of tunnels, elevation of rail lines and building, heightening and strengthening of levees.

Adaptation options in water traffic to an increase in extreme weather events are construction, heightening and strengthening of seawalls to protect harbours from surges and damage, the strengthening of harbour infrastructure to protect from wave damage and storm surges and the dredging of channels. An important autonomous adaptation measure in inland water ways can be the adjustment to a greater variability in water levels. Long drought periods as well as heavy rains may temporarily make water traffic impossible. Beside technical adaptation measures like lowering the gauge of ships one can also expect (to a lower degree) behavioural adaptation like a diversification of transport means for the raw material supply.

To adapt to an increase in heat days in air traffic the development and use of new heat-resistant runway pavement materials and the expansion of runways length at hot-weather airports with insufficient runway length is necessary. Adaptation options to an increase in extreme weather events are an increase in drainage capacity supporting runways and hardening of terminals and other facilities (Transportation Research Board 2008). Table 9 pictures expected adaptation measures for Germany.

Table 9: Autonomous and planned adaptation measures in the transport sector.

Impact	Adaptation measure	Autonomous		Planned	Nature of adaptation	
		Consumer	Producer	Public	Proactive	Reactive
Extreme weather events	Upgrading of drainage systems and increases in pumping capacity of tunnels			X	X	
	Protective constructions, more resistant materials for roads, airport runways, and railways			X	X	
Increased risk of accidents in summer because of loss of concentration	Changed drivers' behaviour	X				X
Land slides and erosion in flood endangered areas	Elevation of roads and rail lines			X	X	
	Building, heightening and strengthening of levees and dikes			X	X	
	Early warning systems			X	X	
	Monitoring and maintaining road and rail infrastructure			X	X	
	Relocation of roads and railways		X	X	X	
	Rock protection measures			X	X	
Disturbance of inland navigation due to low and high water	Diversification of transport means		X		X	X
	Upgrade of canals			X	X	
	Reconsideration of river regulation measures and other adaptation measures			X	X	
	Rethinking of alternative ship construction		X		X	
Shortening of ice and snow cover period	Less winter maintenance for road and rail networks			X		X
General impacts	Research and development		X	X	X	
	New planning norms and guidelines for road and railway construction			X	X	

4.6. The fiscal effects of adaptation

This section is based upon the estimates of adaptation costs presented in section 4.5, and particularly focuses on the fiscal effects of these adaptation costs.

For the most parts, the quantitative results on the fiscal effects of adaptation in this case study on Germany are based on the recently published report of Bräuer et al. (2009). To date this study is the only comprehensive analysis of the fiscal effects of climate change in Germany. The authors stress several times that the quantitative results reflect a high degree of uncertainty, and some of the methods applied in that study rely on questionable and simplifying assumptions. However, some important findings of the study referring to the fiscal costs of climate change are to a certain degree reliable:

- Fiscal costs around the year 2050 will be relatively small, but will significantly rise until 2100 and will then be comparable to the fiscal burden which arises from the current demographic development.

- There are positive and negative fiscal effects in Germany. Positive impacts arise particularly in the tourist sector – however without considering regionally disaggregated impacts which might be interesting for Germany. Negative effects arise in the field of inland floods and in impacts through so-called international channels (mainly climate change-induced effects on the demand for export goods from Germany, but also migration pressure and capital and foreign currency flows).

- Indirect fiscal effects of climate change that follow from an altered available income of consumers or forced investment in less productive capital are much higher than direct effects that are composed of government expenditures or revenues. The study calculates a fiscal burden of direct effects of 3.4 – 15.9 billion € p.a. at the end of the century, but indirect adverse effects on tax revenue amounting to 22.9 -104.6 billion € p.a.. The highly uncertain effects on public budgets are much more relevant than the short-term direct expenditures, which are by nature easier to estimate. The same holds true for fiscal effects of adaptation measures.

As mentioned, these findings refer to fiscal costs of climate change, which are connected with, but different from the fiscal costs of adaptation to climate change. Nevertheless, the study gives an insight in the uncertainties and difficulties of measuring climate-induced fiscal effects, and shows which sectors are the most vulnerable and therefore most relevant for adaptation responses. The fiscal costs of climate change can also be seen as an indicator for the magnitude of fiscal adaptation costs, although it may not be interpreted as an upper limit of public adaptation costs.[20] If there are fiscal effects of pure adaptation measures indicated explicitly, they are mentioned in the respective previous subchapters. It becomes clear that to date most data on quantitative fiscal effects of adaptation is available on the direct fiscal effects of coastal protection investments. Many other implications are very uncertain by now, and in some sectors even the sign of the climate change impact is not sure (e.g. agriculture and forestry).

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[20] Assume the following: There is no adaptation and climate change causes huge damage to the private economy. However, the direct fiscal burden of climate damage is not so high. Though, as the governments acts as a social planner and not as a profit maximising entity, there can be the situation when it decides to spent resources on adaptation, as long as the social benefit is higher than the social costs. These conditions are often met in the case of coastal protection.

5. Case study II: Climate change impacts and adaptation in Finland

5.1. National Adaptation Strategy

Finland has a relatively long history of national programmes dealing with climate change, compared to other European countries. In 2001, the official National Climate Strategy mainly dealt with mitigation strategies to reduce greenhouse gases. But earlier than other nations, the Finnish officials also recognised the inertia of international climate policy and the resulting need in national adaptation strategies to deal with climate change impacts on the biological and socio-economic environment. “Finland’s National Strategy for Adaptation to Climate Change” (NAS 2005) was published in January 2005 by the Ministry of Agriculture and Forestry as the first National Adaptation Strategy in the world.

In 2009, the Ministry of Agriculture and Forestry released an evaluation report on the progress of adaptation in Finland, mentioning that on a scale from 1 to 5 (1 for adaptation least developed, 5 for best developed adaptation policy) Finland reaches a 2 on an adaptation indicator scale (Ministry of Agriculture and Forestry 2009). Particularly, adaptation to climate change is integrated in decision processes in the water resources sector, but also other sectors as transport, community planning, agriculture, and forestry the awareness and consideration of adaptation is quite high, whereas in other sectors still much needs to be done.

FINADAPT (FINADAPT 2007) is another federal program dealing with climate change adaptation, co-ordinated by the Ministry of Environment. Its studies were carried out during 2004-2005. Funded for the period 2004-2005 as part of the Finnish Environmental Cluster Research Programme, it began its work at about the same time when the NAS went into its final phase. It sought to address both scientific and policy needs by conducting an investigation of the adaptive capacity of the Finnish environment and society to the potential impacts of climate change.

At present, Finland is going into another round of adaptation assessment with the “Climate Change Adaptation Research Programme” (ISTO), running from 2006 to 2010. The ongoing research is divided into several projects which basically deal with agriculture, forestry, biodiversity, water management and flood risks, land use and urban planning. The programme is expected to provide additional useful results regarding the costs and fiscal implications of climate change adaptation activities.

5.2. Climate and its trend in Finland

5.2.1. General overview

Annual mean temperatures in Finland increased by about 0.7°C in 1901–2000 (Jylhä et al. 2004) which is close to the worldwide upward trend in mean temperatures (IPCC, 2007). The majority of global warming over the last 50 years is believed to be caused by increased concentration of greenhouse gases. Nonetheless, as Jylhä et al. (2004) point out, one cannot rule out natural climate variability as a source of the observed upward temperature trend in Finland. Based on the literature, appearance of climate extremes will occur more frequently although the frequency is commonly unknown and consequently hard to predict.

To get an impression of possible future climate change in Finland, one can draw on available regional climate change projections. Studies dealing with regional projections were conducted by the FINSKEN Project (Jylhä et al. 2004) and FINADAPT (Ruosteenoja et al. 2005). The sets of climate projections are composed by the IPCC SRES A2 and B1 scenarios in both projects. The A2 storyline describes a very heterogeneous world with increasing global population and regionally orientated economic growth and technological change that is slower than in other storylines. The B1 scenario family represents a convergent world with moderate population growth but rapid changes in economic structures towards a service and information economy. Implied are a reduction in material intensity and the introduction of clean and resource-efficient technologies. The B1 storyline can be interpreted here as the "sustainability" scenario whereas the A2 storyline corresponds to a "retrenchment" scenario, as a growing population in combination with slow technological change possibly implies constraints in resource consumption. The reason for choosing these scenarios as significant for climate change modelling in Finland is discussed in Carter et al. (2005).[21] For the sake of completeness, the A1 scenarios are also used in some studies. In particular, Perrels et al. (2005) judge the A1 scenario family as useful in its quantitative analysis because important sectors like agriculture and tourism provide quantitative information only for the A1 scenario family. The resulting socio-economic development in the three scenarios is illustrated in Table 10.

Table 10: Demographic and economic trends in Finland according to the FINADAPT scenarios until 2050. Source: Perrels et al. 2005.

SRES Scenarios	Variables	Annual growth rates	
		1990 – 2020	2020-2050
A1B or A1T (Global markets)	Population GDP GDP/capita	0.28 % 2.25 % 2.00 %	-0.18 % 2.10 % 2.30 %
A2 (Retrenchment)	Population GDP GDP/capita	0.28 % 1.65 % 1.40 %	-0.18 % 1.05 % 1.20 %
B1 (Sustainability)	Population GDP GDP/capita	0.28 % 2.10 % 1.80 %	-0.18 % 1.50 % 1.70 %

5.2.2. Changes in detail

5.2.2.1. Temperature

According to Jylhä et al. (2004), the annual mean temperature is projected to rise by 1.3 – 3.1°C by the late 2020s, relative to the baseline period of 1960-1990 (Figure 19). By the 2050s the corresponding increase is 1.8 – 5.2°C. In the FINADAPT studies[22], the corresponding increases in the A2 and B1 scenarios are 1.3 – 2.8°C as by 2020 and 1.8 – 4°C by 2050.

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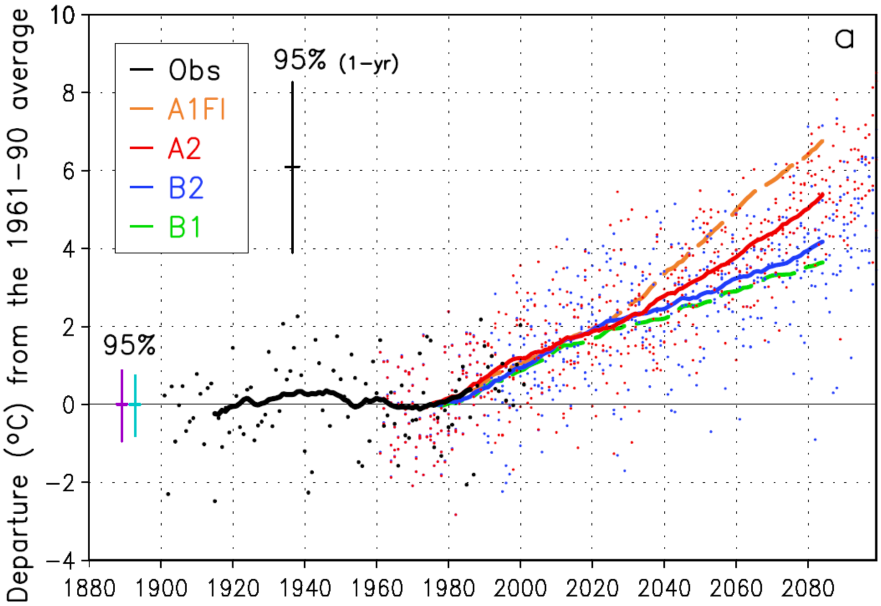
[21] The FINADAPT scenarios slightly differ from the SRES scenarios. The regional adjustment of scenarios to Finland is covered in Carter et al. (2005) and Ruosteenoja et al. (2005).

[22] For a discussion see Ruosteenoja et al. (2005).

Figure 19: Temperature change projections for Finland in °C during 21st century. All curves are 30-year running means.



The black dots denote annual average temperature observations; the blue and red dots denote multi-model average responses to the B2 scenario and the A2 scenario, respectively. The coloured bars indicate the 95% confidence interval of statistical significance for changes in the 30-year mean for two different projection models. The black bar shows the 95% range of observed inter-annual variability in 1961-1990, as a plausible measure of the year-to-year variation around the curves for the A1FI and B1 scenarios, since no annual values for them were plotted. Source: Jylhä et al. 2004.

Ruosteenoja et al. (2005) calculate a slight temperature increase in the range of 1°C for the upcoming period until 2020. However it should be stated that the obtained standard deviations are 0.6-0.9°C in winter and ~0.3°C in summer, about one half of the projected mean value. Over such a short time span, natural climatic variation and climatic change are hard to distinguish from each other. But even such a small temperature increase would increase the number of hot days, defined as a summer day with a temperature maximum greater than 25°C, by 35 - 43%.

For the end of the century, climate in Finland is predicted to be very different than today. In the A2 scenario (retrenchment), mean temperatures are projected to rise by 4°C in summer and 6°C in winter. With rising temperatures, the length of the frost-free period may increase by 2-2.5 months although these values are derived under severe uncertainty. A large increase in wintertime temperatures, especially significant on very cold days is also supported by Kjellström (2004): the temperature on coldest days is expected to change more than average.

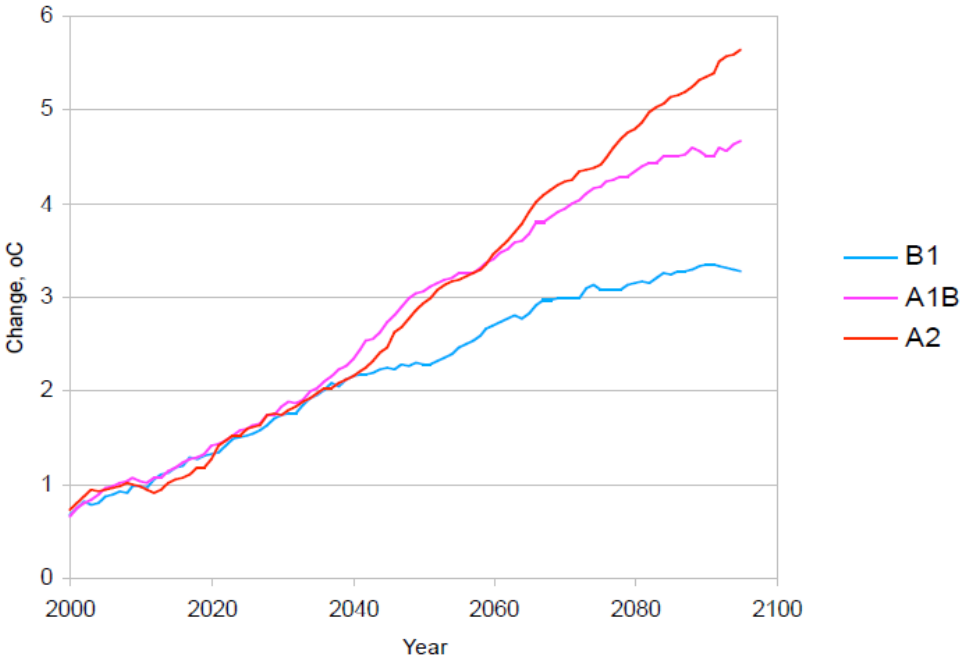
An overview of simulated changes in average temperature (and precipitation) for the FINADAPT A2 and B1 scenarios is provided in Table 11.

Table 11: Simulated changes in mean surface air temperature (in °C) and precipitation (in %) in Finland for two 30-year time periods, relative to the baseline period 1971-2000. Standard deviations are given in parentheses. Source: Carter et al. 2005.

Time period	Temperature (°C)		Precipitation (%)	
	1991 – 2020	2021 – 2050	1991 – 2020	2021 – 2050
December – February				
A2	1.1 (0.8)	2.6 (0.8)	4.7 (5.3)	9.7 (6.9)
B1		2.5 (0.7)		7.3 (7.0)
March – May				
A2	1.1 (0.6)	2.2 (0.9)	3.8 (4.2)	7.3 (7.3)
B1		1.9 (0.9)		7.6 (6.6)
June – August				
A2	0.6 (0.3)	1.5 (0.4)	1.9 (2.7)	4.1 (3.0)
B1		1.3 (0.3)		2.8 (4.0)
September – November				
A2	0.7 (0.5)	1.8 (0.5)	1.4 (2.8)	5.5 (3.4)
B1		1.6 (0.3)		5.1 (1.5)
Annual				
A2	0.9 (0.4)	2.0 (0.4)	2.7 (2.1)	6.4 (2.4)
B1		1.8 (0.4)		5.4 (2.7)

Recently, updates of the regional climate projection models for Finland were published (Jylhä et al. 2009 (in Finnish), cited by Ministry of Agriculture and Forestry 2009). In terms of mean temperature development, no major changes can be accounted, as illustrated in Figure 20.

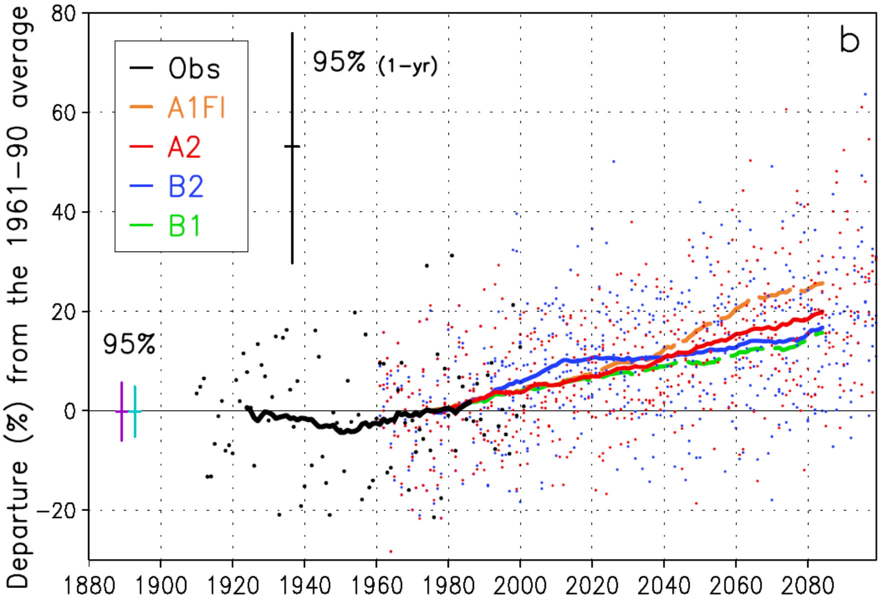
Figure 20: Annual temperature change, compared to the baseline period 1961-1990, depending on three IPCC-scenarios. Source: Jylhä et al. 2009 (in Finnish), cited by Ministry of Agriculture and Forestry 2009.



5.2.2.2. Precipitation

Table 11 also shows that climate change is expected to increase precipitation in Finland. Most estimates predict higher rainfall in winter. Also Jylhä et al. (2004), who combine six different projection models and four different scenarios, come to this conclusion. According to their projections, in the A2 and B1 scenarios the annual mean precipitation is expected to increase by 2 – 16% by 2039 and by 1 – 21% by 2069 relative to the baseline period 1961 – 1990. As can be seen from the numbers, the variability in projected precipitation changes is high and the extent depends strongly on the used scenario and its implicit storyline. However, rainfall is expected to increase mostly in winter with no significant change in summer.

Figure 21: Precipitation change projections. For an explanation of the graph see Figure 19. Source: Jylhä et al. 2004.

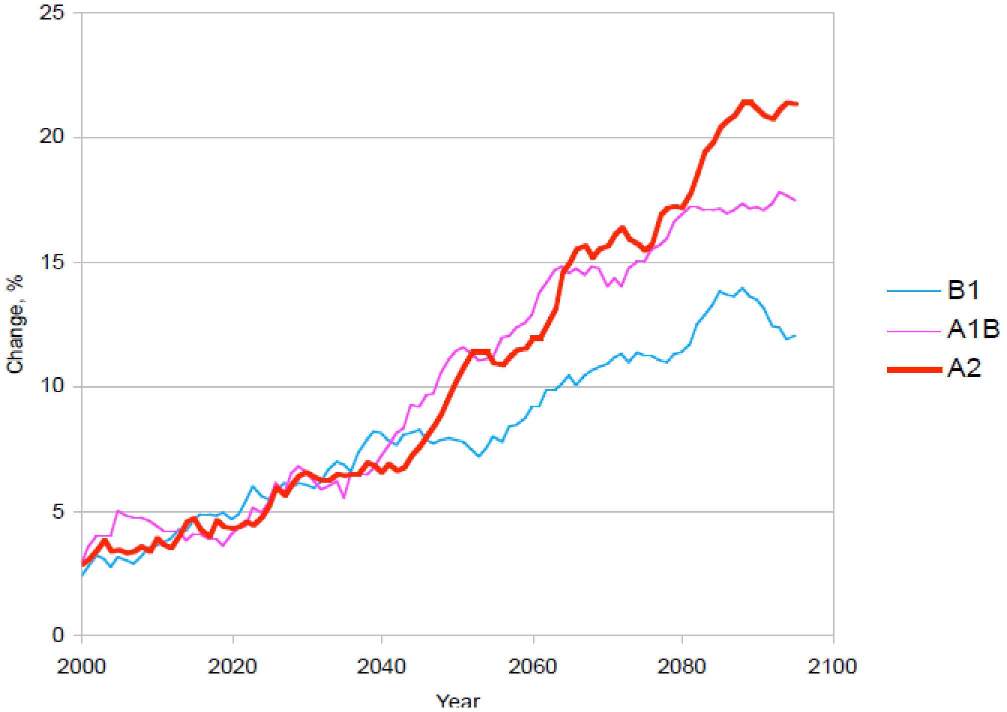


An overview of simulated changes in average precipitation (and temperature) for the FINADAPT A2 and B1 scenarios is provided in Table 11.

Moreover, with the increasing precipitation also the appearance of torrential rain is likely to increase (Tuomenvirta et al. 2000 and Räisänen et al. 2001).

Figure 22 shows that for the precipitation projections some changes to a less severe increase could be observed during the last years. However, the long term tendency to a wetter climate in Finland is still very clear.

Figure 22: Projection of annual precipitation, relative to baseline period 1961-1990, depending on three IPCC-scenarios. Source: Jylhä et al. 2009 (in Finnish), cited by Ministry of Agriculture and Forestry 2009.

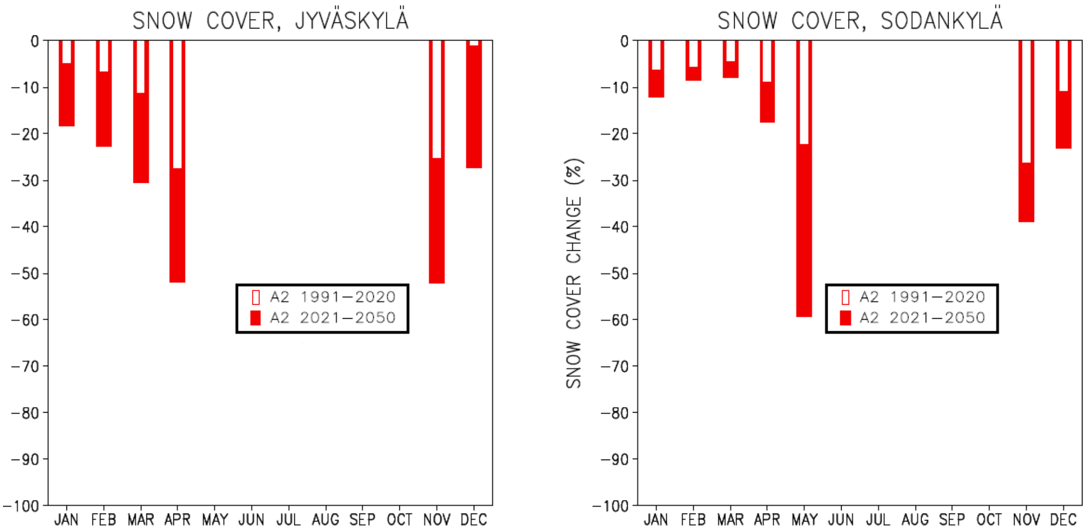


5.2.2.3. Snow Cover and ground frost

Changes in the snow amount in a significant range are not likely to happen until 2020. But as going towards midcentury, a considerable decrease in snow cover can be expected, with a particular strong reduction at both ends of the season. As Ruosteenoja et al. (2005) state, until 2050 snow amount during midwinter is projected to decline by more than 20% in Southern Finland and around 10% in Northern Finland in the A2 scenario (Figure 23). The changes are becoming larger when moving towards the end of the century with a huge decline in Southern Finland.

It must be considered that whatever the projections say, one can identify two opposite driving factors affecting the snow amount. On the one hand, the increasing temperatures combined with a larger proportion of precipitation in a liquid state tend to reduce the snow cover. But then, increasing wintertime precipitation with still sub zero degrees Celsius temperatures are enhancing snowfall. The latter is especially relevant in Northern Finland. Still, the net effect of both opposite driving factors is expected to be negative, as it can be derived from Figure 23.

Figure 23: Snow cover projections for two weather stations in Southern Finland (Jyväskylä) and Northern Finland (Sodankylä). Source: Modified adapted from Ruosteenoja 2005.



Venäläinen et al. (2001) estimate changes in ground frosts at the end of the century. Less snow cover combined with higher temperatures, which works as efficient thermal insulator retarding ground frosting, has ambiguous effects on ground frost. The increase in temperature will reduce ground frost directly on the one hand but less snow cover will cause ground to be laid open resulting in a higher vulnerability to ground frost. The expected temperature rise in Northern Finland is likely to decrease ground frost whereas in Southern Finland, frost layer is expected to become slightly thicker and could penetrate deeper than present in severe winters.

5.2.2.4. Windiness and solar radiation

Ruosteenoja et al. (2005) find that changes of wind velocity are almost not statistically significant. They conclude that on the basis of their present model data it's not possible to say whether wind will lessen or intensify in the future. With a regional Baltic Sea climate model, an increase of wind velocity in the Baltic Sea region is going to happen as sea ice is expected to decline (Räisänen et al. 2003).

The measurement of solar radiation is controversial due to problems with implementing cloudiness in climate models (Mc Aveney 2001), which implies a great amount of uncertainty. However, Ruosteenoja et al. (2005) report an approximate 10% increase of solar radiation in Southern Finland in the summer. For other seasons as well as Northern Finland, no significant results are presented.

5.3. Impact assessment and adaptation strategies in critical fields

5.3.1. Agriculture

The gross value added by agriculture (including forestry), hunting and fishing in Finland accounts for 3.2% of the GDP in 2007 (EUROSTAT country profile 2007). Thus, the importance of the agricultural sector for the national economy can be considered as low. However, the sector is generally expected to gain from climate-change-induced environment transformation.

Physical impacts

First of all, the increases in temperature can substantially prolong the growing season (Hilden et al. 2005). Milder winters and spring seasons substantially decrease the risk of early seeding. Therefore, crop types of which yield is currently constrained by too cold climate or too short vegetation periods could cause an increase in cereal yield. Another advantage is a higher atmospheric CO_2 concentration, which enhances plant growth through accelerated photosynthesis and biomass accumulation. Higher CO_2 concentration also moderates the effect of droughts, as the stomata[23] of plants close to some extent which leads to less water loss. Additionally, higher mean precipitation provides a favourable background environment for enhanced plant growth.

Although agriculture is expected to gain from climate change there are potential negative effects as well, which could outweigh the gains to some extent. Extreme weather events such as droughts and sudden rainfall are potential harmful factors for crops. A combination of higher temperatures, accelerating microbial activity in the soil, and higher rainfall leads to nutrient leaching and problems due to soil erosion. But the largest adverse effect is likely to be created through an increased occurrence of pests, pathogens and weeds which could reproduce at higher rates than today.

Economic impacts

Hilden et al. (2005) state that a simple increase or decrease in yield alone is not very significant and will not, according to a preliminary model-based analysis, have major structural effects on Finnish agriculture. As they are pointing out, “one should realise that the market prices for products as sugar beet, rye and oilseeds do not even cover variable production costs in Finland” (Hilden et al. 2005 p. 17).

Perrels et al. (2005) provide some ideas about the possible economic impact in the agricultural sector. Generally, relatively small gains are expected. The increase in mean precipitation, temperatures and CO_2 concentration enhances plant growth. By and large, it appears that the favourable effects of accelerated plant growth will dominate over the unfavourable effects of loosing biodiversity and the increased risk of pests and diseases in plants and animals. Nevertheless, as Hilden et al. (2005) are pointing out, crop yields alone do not ensure a rapid increase in farm income due to the fact that market influences and EU subsidies play an important role in agriculture business. Without policy changes,[24] Perrels et al. (2005) calculate the change in net value added as 60 million € in 2020 and 100 million € in 2050 respectively.[25] The assumption is that increases in cereal production are used to support the expansion of pig farming. This requires that the current EU subsidy scheme remains in force as it is at present. However, a reduction in subsidies can be interpreted as a gain for consumers as fewer taxes have to be paid. This offsetting result regarding an overall welfare effect is not assessed in the study. Regardless the obtained positive results, the authors caution against a simple imagination of a higher income in agriculture due to possible higher crop yields, e.g. when the market environment does not necessarily produce enough demand for higher production. Additionally, a small domestic market and long distances to world markets hinder the sales volume to expand. Small size of field parcels add up to the number of climate

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[23] In botany, a stoma is a pore, found in the leaf that is used for gas exchange.

[24] The main assumption here is that the current EU and national subsidy support schemes remain in force.

[25] Details of effects are provided in table A1 in the Appendix.

change unrelated handicaps which play an important role in determining the future income of the agricultural sector in Finland.

The main conclusion is that if climate change is accompanied by an increase of demand and keeping the current subsidy scheme in force, a low net gain in agriculture is possible.

Adaptation in the agricultural sector

In general the agricultural sector is assumed to adapt autonomously without planned adaptation efforts. This is also in line with global estimates by IMF (2008), which predict an 85% ratio of autonomous adaptation in total adaptation in agriculture, forestry and fishery. The main results are provided in Table 12. The table lists expected impacts for the agricultural sector and assigns corresponding adaptation measures to indicate possible reactions from different actors. Further classification distinguishes between two types of market actors, consumers and producers, and public intervention denoted as planned adaptation. For an extended view on adaptation processes, the question of timing of adaptation actions is included in the last column. Proactive actions are those, which are to minimise the economic consequences of physical damage before it actually occurs. In contrast, adaptation responses which are supposed to moderate economic costs after the physical damages have occurred are classified as reactive. However, the classification into proactive and reactive adaptation should be considered with precaution. Another distinction criterion might be the effect of specific measures, whether they are implemented to reduce the physical damage on the one hand or the economic damage on the other hand. In line with PART I, we apply the timing approach; thus proactive adaptation measures are defined as measures taken before the damage occurs, while reactive measures are taken after the incidence. Note that many measures by nature are possible at both stages - before and after the occurrence of the damage event, so a distinction or proactive vs. reactive can never be very sharp.

Public intervention in the Finnish agriculture sector is mainly characterised by awareness building and provision of information about climate change. Furthermore, from the public policy point of view, there is some attention required to intervene in the adaptation process when social costs exceed private costs. In the agricultural sector, the current legislation in Finland restricts the land tenancy period to ten years (Hilden et al. 2005). The short period not only leads to insecurity but also provides little incentive for investments in drainage systems of fields or other improvements. Here there might be a need for a framework to facilitate desirable adaptation measures and to internalise external costs of private adaptation.

For the recovery of residual climate damages, e.g. after extreme weather events like droughts or extreme rainfalls, insurance schemes may play an important role. By now crop yield insurances are not so familiar in Finland, as Lehtonen and Kujala (2007) mention. According to the authors, the reason is the relatively small average size of Finnish farms, which implies high transaction costs for any risk reducing instruments like insurances. If yield variances increase due to more frequent extreme weather events insurances are expected to become more demanded. This means, however, besides private costs for risk reduction also government expenditure may rise, as subsidies of crop insurances are a widely used policy measure to reduce risks in agriculture (OECD 2005).

Another reactive adaptation measure is the use of plant disease and pest monitoring systems, since it cannot prevent diseases and pests, but limit their economic costs to a minimum. In the case of such monitoring systems, private benefits are generally smaller than private costs, and state intervention becomes necessary in the provision of this good. Beside, a disease monitoring system only makes sense on a larger (national) scale and therefore constitutes a public task.

Residual economic damages (after reactive adaptation) are uninsured yield risks, yield and soil losses due to extreme weather events and other unavoidable negative effects on yields and revenues.

Table 12: Specific impacts and adaptation responses in the agricultural sector.

Specific Impact	Adaptation measure	Autonomous		Planned Adaptation	Nature of adaptation	
		Consumer	Producer		Proactive	Reactive
Longer growing season	Earlier start of growing season (seeding)		X			X
	Expanding variety of crops and plants		X		X	X
	Developing of new crop types		X		X	
Extreme events e.g. rainfall	Redesigning drainage systems		X		X	
	Rethinking short land tenancy period			X	X	
	Evaluating water protection guidelines			X	X	
	Use of insurance (possibly subsidised)		X	(X)	X	
Drought	Use of irrigation systems		X		X	
General impacts	Research on regional climate change			X	X	
	Increased use of fertilisation and plant protection (neg. externalities)		X		X	X
	Development of plant and animal disease and pest monitoring systems			X	X	
	Considering new insurance regulation			X	X	

5.3.2. Forestry

Finland's total area of forest land is 26.3 million ha, which relates to 87% of the total land area (Kellomäki et al. 2005). The Finish round wood production contributes to about 12% of the EU-27 production and is the third biggest producer after Sweden and Germany. The abundance of forests combined with a small population gives an idea about the importance of the forest industry. In per capita terms, Finland is the second biggest round wood producer, the biggest sawn wood[26] producer and the biggest paper and paperboard producer in the EU-27 in 2005 (Eurostat 2008).

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[26] Sawn wood is wood that has been cut into pieces and exceeds 6mm in thickness.

Private, non-industrial forest owners keep about 52% of total forestry land. The rest divides into land owned by forest industry (8%), the government (35%), and municipalities and parishes (5%). Private forest estates are relatively small; in average one estate has a size of 24 hectares. Consequently, the number of private forest holdings is relatively large (440,000 of at least two hectares).

Forest management is based on the Forest Act which was reformed in 1997 and aims at securing the economic, social and ecological sustainability of forestry. On this basis, a private forest owner may receive financial support from the government for forest management and improvement work as well as for wood harvesting and transportation used in energy productions.

Physical impacts

The increase in temperature, carbon dioxide concentration and precipitation due to climate change will accelerate the growth of trees in the boreal forest and the timberline is expected to move north between 150 and 550 km by the end of this century (NAS 2005). Naturally, the migration rate for trees is only about 20 to maximum 200 km a century.

On the other hand, there is a possible increase in forest fire risk due to longer summers in the future. Moreover, the lower likelihood of ground frost, which anchors trees better to the soil, and increased frequency of storms add up to expected higher damage of trees.

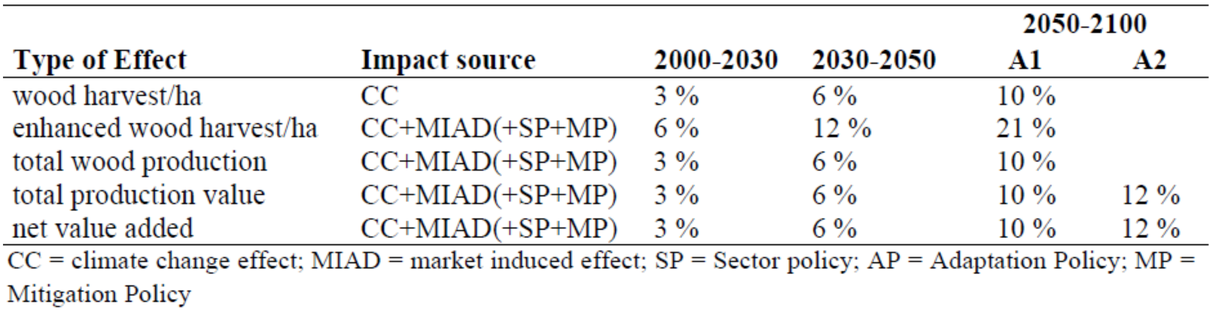
The productivity of forests could increase potentially. In an assessment based on simulations by a forest ecosystem model (Kellomäki et al. 2005), the most Northern and most Southern parts of Finland are affected the most. Especially in the North, productivity could increase substantially. The composition of tree species is expected to change with birch and scots pine displacing Norway spruce particularly in Southern Finland.

However, there are several factors leading to uncertainty problems in qualitative impact assessments (Kellomäki et al. 2005). The mortality of trees is endogenously related to the biological life cycles of trees and exogenously related to the abiotic (frost, wind, snow, fire) and biotic (insect and fungal pests) factors. Eventually, the possibility of a higher ozone concentration is not well understood yet. Furthermore, higher precipitation in winter could enhance fungal decay of roots which in turn could not be compensated sufficiently in summer due to periodical water scarcity. So the combination of wet and warm winters and dry summers is very conducive to fungal attacks.

Economic impacts

With growing opportunities, the timber industry could substantially gain from climate change. Kellomäki et al. (2005) project the total growth due to climatic changes at 22.7 million m^3 in 2050 (which equals an increase of 28%), with a much larger increase of 42% in Northern Finland. Perrels et al. (2005) calculate a change in net value added of 75 million € in 2020 and 150 million € in 2050 respectively. The main assumptions are that the sector cost structure remains the same and unit-prices are constant throughout the analysed time period. Details of the effects are given in Table 13:

Table 13: Production effects in forestry. Source: Perrels et al. 2005.



				2050-2100	
Type of Effect	**Impact source**	**2000-2030**	**2030-2050**	**A1**	**A2**
wood harvest/ha	CC	3 %	6 %	10 %	
enhanced wood harvest/ha	CC+MIAD(+SP+MP)	6 %	12 %	21 %	
total wood production	CC+MIAD(+SP+MP)	3 %	6 %	10 %	
total production value	CC+MIAD(+SP+MP)	3 %	6 %	10 %	12 %
net value added	CC+MIAD(+SP+MP)	3 %	6 %	10 %	12 %

CC = climate change effect; MIAD = market induced effect; SP = Sector policy; AP = Adaptation Policy; MP = Mitigation Policy

Adaptation in the forestry sector

Whereas the knowledge base of climate change impacts in the forestry sector is quite good, research concerning adaptation into forestry has not been conducted that often. This can be seen critical as the time lag of activities done today is determined by the growth speed of trees.

Regarding planned vs. autonomous adaptation, one could argue that adaptation of producers automatically implies state activity, since 40% of the forest area is owned by the government, municipalities or parishes. But here planned adaptation means the activity of a central agency which has in mind public benefits. Fiscal effects, however, may occur from government activities as a social planner as well as impacts on the productivity of the state-owned forests. Thus, one can assume slight beneficial budgetary effects from climate change impacts in the forest sector.

All presented adaptation measures are proactive in the sense they are supposed to minimise the impact of physical damages in forests before they occur or to make maximal use of beneficial changes. Another reason why adaptation in forestry is anticipatory is the long investment horizon, given by the natural growing conditions. Residual damages are mainly to be expected in the field of forest fires, which probably cannot be ruled out effectively and may cause considerable economic costs. However, the residual damages in the Finnish forestry sector as a whole expectedly can be overcompensated by yield gains because of improved growing conditions. Moreover, if the forest fire risk can be insured, there might be positive net effects even on firm level throughout the sector, given the current relative prices.

Table 14: Specific impacts and adaptation responses in the forestry sector.

Specific Impact	Adaptation measure	Autonomous		Planned Adaptation	Nature of adaptation	
		Consumer	Producer		Proactive	Reactive
Change of favourable conditions for certain tree species	Cultivation of more productive tree populations		X		X	
	Use of alternative genotypes to prepare for different future scenarios		X		X	
Possible increase in forest fires	Developing monitoring systems		X	X	X	
	Defining fire breaks in forest management		X		X	
	Reconsidering normative framework for fire breaks			X	X	
	Rethinking of precaution measures (not concretised)		X	X	X	
Change in environmental conditions	Rapid harvesting after wind damages		X	X		X
	Inclusion of climate change aspects in the National Forest Programme			X	X	
	Developing of higher resolution climate change models suitable for regional projection			X	X	
	Research and Development of new harvesting techniques and tree improvement		X	X	X	
Less frost – difficulty of harvesting in muddy conditions	Expansion of road networks			X	X	
Increase of biotic risks	Control of pests and diseases			X	X	
	Enhance resistance of forest by mixed stands		X		X	
General impacts	Reconsidering the cultivation of foreign thermophile species		X	X	X	
	Forest transformation to higher diversification of tree types		X		X	
	Field mapping and regional cultivation recommendation			X	X	
	Rearing more resistant tree types		X	X	X	
	Knowledge transfer of experts			X	X	
	Evaluation of current water management concepts			X	X	

5.3.3. *Water (floods, sea level rise, water resources)*

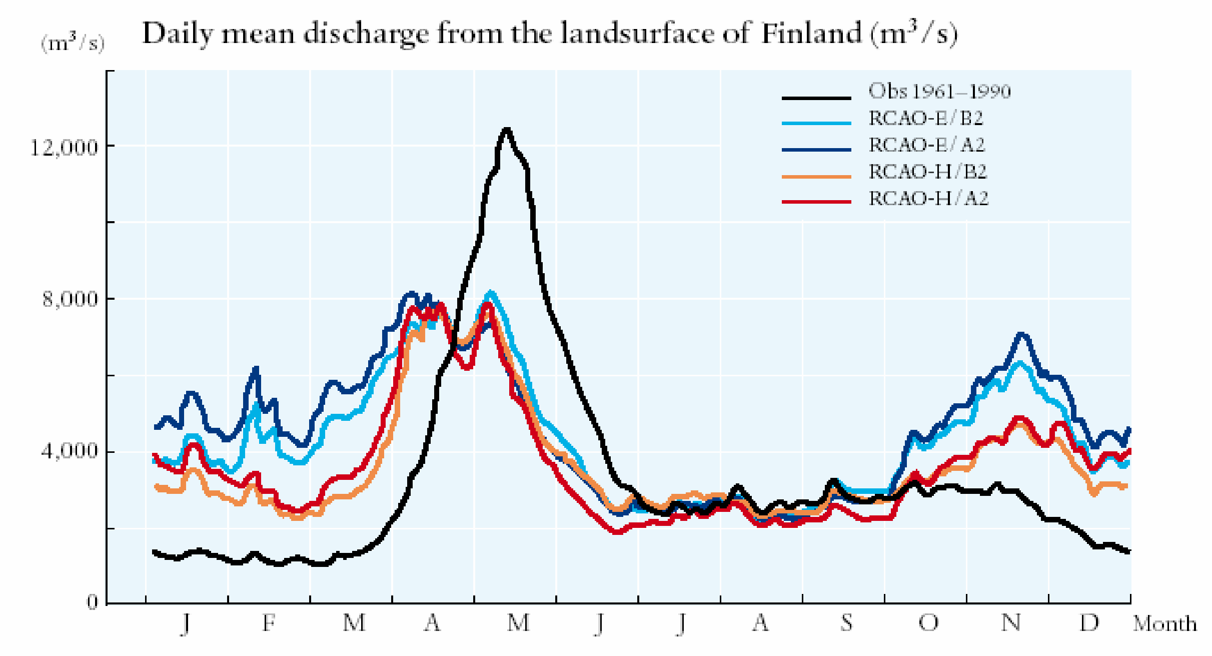
Compared internationally, water resources in Finland are abundant and of high quality. Naturally, the care for water resources is of high public interest. Therefore the cost of maintaining clean water can be associated with the fiscal side of governments.

With more than 14,000 km, the total Finnish coastline is relatively long. 50% of the GDP and 57% of the Finnish population are located in a 50 km zone from the coastline. Although, vulnerability towards sea level rise is considered to be low, as explained in the following sections. Main results in the following section are taken from Silander et al. (2006).

Physical impacts

In Finland a change in seasonal and regional distribution of runoff can be expected. In Northern Finland spring floods are expected to increase due to increased snowfall. Southern Finland will experience fewer floods in spring while having more runoff in winter. Extreme runoff events are more likely to occur but hard to predict. Figure 24 very clearly shows the decline of expected runoff in spring, due to an earlier snow melting, and the consequent higher discharges in winter time. In this graph which depicts mean values, extreme precipitation events cannot be illustrated.

Figure 24: Daily mean discharge from the landsurface in m³/s.



Two IPCC scenarios combined with two GCMs for the period 2071-2100, relative to the baseline period of 1961-1990. Source: Clausen 2007.

To the best of what is known from climate models, longer summers which are likely to be drier than today could potentially occur more often, which will have a negative impact on the groundwater level.

The quality of surface waters could be affected as well. Floods and droughts are said to potentially increase due to climate change. In the case of droughts, low flows in watercourses imply higher concentrations of bacteria, algae and toxins. On the other hand during high flows, chemical leaching, soil erosion and urban pollution come as negative side effects. In coastal waters in South and South-West Finland, nutrient leaching leads to eutrophication.[27] Additionally, in cases of droughts algae blooms would become more frequent and groundwater discharges would be reduced, probably leading to bad quality of water (Silander et al. 2005 p.1 etc.). As regarding water supply and waste water, no new types of threats will become widespread, although present problems (shortages in water supply due to extreme droughts, capacity problems in sewer systems due to heavy rainfalls) could become more frequent.

The consequences of heavy rainfall can be at most expected in urban centres, containing basement flooding, sewage water showing up in drinking water and dirty rivers. Potentially, the design of current water and wastewater infrastructure needs to be reconsidered in case of shortfalls. In particular, storm water drainage systems could need improvement as they are mainly designed on the basis of historical observed records which might provide a bad estimate for future expected increased precipitation.

Based on a study by Johansson et al. (2004), the rise in sea water level is projected to partly outweigh a tendency of land uplift in the Gulf of Bothnia[28], thus the past trend of relative sea level decline slows down. Moreover, on the Gulf of Finland, the land uplift rate even is expected to be cancelled out by a sea level rise. According to Policy Research Corporation (2009), the sea level rise is estimated between -20 cm and 50 cm for Helsinki at the Gulf of Finland, whereas it can remain negative at Kemi in the Gulf of Bothnia (between -75 cm and -5 cm). Moreover, coastal erosion is not an issue in Finland as the coast is mainly of a rocky and clay nature.

Anyway, the uncertainties in the predictions are large. It can be said, that Finland is not expected to be in big trouble due to sea level rise. But as variability remains high, occasional strong events can cause substantial damage to near coast located infrastructure, buildings, property and humans.

Precipitation can be directly linked with energy production. About 20% of electricity produced in Finland comes from hydropower. As runoff is expected to increase in the future, hydropower production is expected to increase slightly by up to 10% depending on the scenario and availability of land resources (Silander et al. 2006). As precipitation is likely to vary substantially between seasons, more structural strains and erosion of dams are possible.

Economic impacts

The town of Pori is an example of a very sensitive area to flood risk. About 20 km of dikes will probably need to be raised in order to maintain the current safety level in a future with increased risk of extreme floods and sea level rise. This could cost between one and 10 million €.

Extreme wave events in combination with a temporary sea level rise can cause damage in coastal regions. A recent example of such an event is the storm surge caused by strong winds in January 2005 which pushed the average water level up to 2 metres above normal. Hundreds

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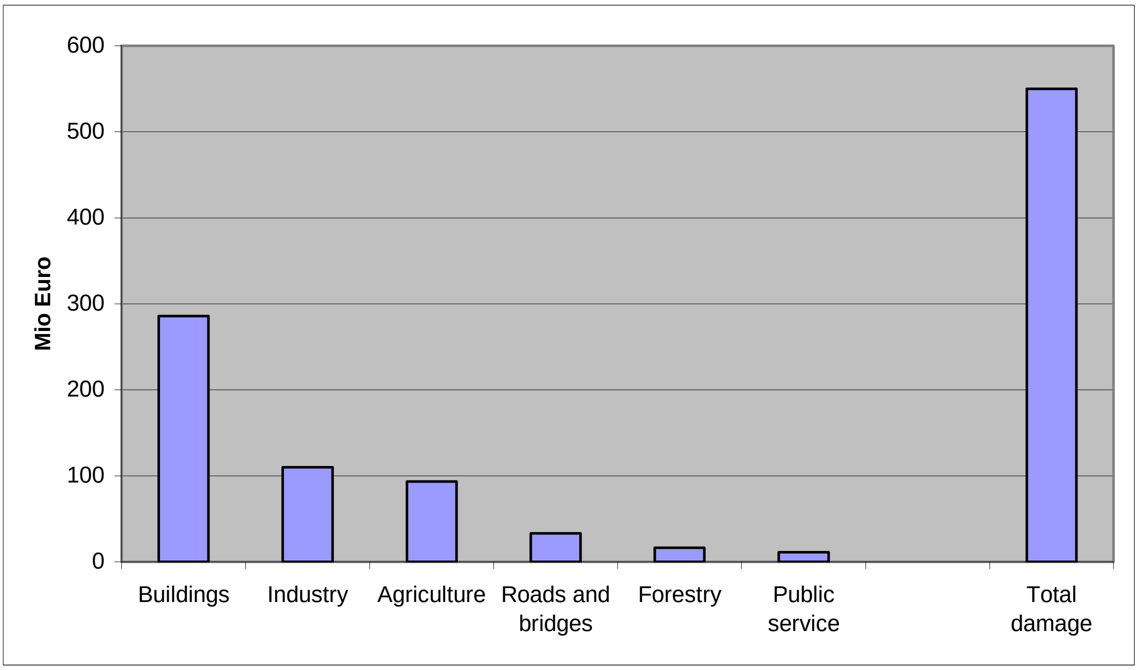
[27] Eutrophication is an increase in chemical nutrients in an ecosystem leading to excessive plant growth.

[28] The land uplift is caused by a postglacial rebound. The land uplift rate is quite constant and reliable, however very different along the Finnish coastline.

of vehicles were flooded in harbour areas and the total damage was estimated to be between 15 and 20 million € (Silander et al. 2006).

In the Extreme Flood Project, flood damage estimates were made for almost 400 risk areas. In the case of floods occurring in all of the risk areas, costs could be up to 550 million € (Figure 25), although the probability of such an event is fairly low (Silander et al. 2006).

Figure 25: Flood Damages according to the Extreme Flood Project using the 1999 price level. Source: adapted from Silander et al. 2006.



Possible effects of longer and drier summers can be studied on the basis of exceptionally dry nine months in 2002 and 2003. A main consequence was water shortage in urban as well as rural areas. It was necessary to transport water to thousands of households in sparsely populated areas. Also inland water traffic was affected. An overview about the effects can be seen in Table 15. The costs in the building sector are that high because of foundation damages due to low groundwater level and leakages of sewage pipelines for the same reason.

Table 15: Estimated damage of the drought in the years 2002 and 2003. * Costs of water supply companies are not included.

Area of Impact	Estimated damage (millions of €)
Water supply and sewerage	8*
Hydropower production	50**
Agriculture	15
Forestry	2
Building	25
Inland water traffic	0.5
Recreational use of water course	1
Total	~102

** Estimate based on additional costs resulting from increased usage of more expensive energy sources. Source: Silander et al. 2006.

In an analysis by Nicholls et al. (2008) focussing on the exposure of population and assets to a 1 in 100 years surge-induced flood, Helsinki is attributed to have currently 6,000 people and assets worth 1 billion US Dollars exposed to such an event. With climate change effects such as global sea level rise, the number of people exposed could more than double by 2070. The exposure of assets could even increase up to 7.74 billion US Dollars, a serious rise in costs of over 670%.

Adaptation in the water sector

Possible adaptation measures referring to specific climate change impacts in respect to water resources are composed in Table 16. Again, the planned adaptation by a public stakeholder mainly refers to information, research and planning tasks. With regard to the adaptation of planning processes in land use and community planning, the awareness and recognition of climate change is quite high, according to the evaluation report of the implementation of the National Adaptation Strategy (Ministry for Agriculture and Forestry 2009). In contrast, construction guidelines have not been adapted to date.

In Finland, there are also private stakeholders caring for flood security to some extent, since coastal zone management is a matter of municipalities and private landowners. They have to bear the costs of coastal protection measures. National authorities provide guidelines on land usage and minimum construction heights of flood constructions, but it is still up to the municipalities to decide on safety margins. However, in Finland "hard" measurement against floods (e.g. dikes and barriers) are not as common as in North Sea or Mediterranean countries. In contrast, the municipality of Helsinki is currently building barriers to protect low-lying areas of the city land. It is remarkable that this protection is only partial; it will not protect low-lying private property outside the city land. These landowners would have to set up their own flood protection (Policy Research Corporation 2009).

In the case of flood protection the differentiation between proactive and reactive measures becomes very illustrative. Proactive measures try to minimise the adverse effects prior to the flood (e.g. dikes and other flood protection measures), whereas reactive measures are to mitigate the economic impacts of an occurring flood event (e.g. emergency management).

Residual damages after floods may be subject to insurances, though there is danger of market failure if the insurance premiums are not subsidised (see section 4.5.1). In contrast, an example from Copenhagen shows the other way of public insurance schemes with compulsory insurance coverage in the total city area (Hallegatte 2008). Under the assumptions of a densely populated port city where publicly provided flood protection is the only feasible counteraction against flooding private households have no possibilities to mitigate or prevent flood costs. Therefore moral hazard in the sense of sub-optimal flood adaptation of insured households is not possible. The adverse selection is not existent in the case of a compulsory insurance, thus the only remaining problem is the calculability of catastrophic events and the questionable applicability of the law of great numbers. These are the remaining reasons why the state instead of a private insurance is insuring in the case of Copenhagen. So the state is responsible for an effective flood protection as well as for compensation payments after floods have occurred in spite of protection. However, the functionality of that system depends on specific characteristics of Copenhagen, such as an effective and comprehensive flood protection of a densely populated city and on the state's willingness to face the risk of a catastrophic event.

According to IMF (2008), costs of coastal protection are almost totally borne by public sources, at least on the global level. Since in Finland there are also private stakeholders in charge of coastal protection, here the ratio of public costs may be a bit lower. Moreover, in Finland adaptation costs against sea level rise are comparable low, since hard measurements play only a minor role and spatial planning and building regulations are more important. In 2008, the national and regional authorities spent only about one million € on coastal protection, whereof the construction of barriers in Helsinki account for half the amount. In total all public expenditure on coastal protection in the period 1998/2015 is estimated to be not more than 8.06 million € (Policy Research Corporation 2009). So here the risk of a major catastrophic event with public ad-hoc relief or the need for a state-run insurance scheme seems to be relatively low to date.

Table 16: Specific impacts and adaptation responses in the water sector.

Specific Impact	Adaptation measure	Autonomous		Planned Adaptation	Nature of adaptation	
		Consumer	Producer		Proactive	Reactive
Inland floods & heavy rains	Raising of flood banks			X	X	
	Expansion of water supply and sewerage networks			X	X	
	Use of insurance	X	X		X	
	Flood-adapted building	X	X	X	X	
	Property construction out of risk area	X	X		X	
	Rethinking of land use in endangered areas			X	X	X
	Evacuation of flood endangered areas	X		X		X
	Urban and land use planning, preparation of general plans for flood risk sites			X	X	
	Research on regional flood occurrence and impacts, SLR monitoring			X	X	
	Early warning systems			X	X	
	Coordination and Cooperation with neighbouring authorities			X	X	
	Improvement of flood protection construction			X	X	
	Emergency Management			X		X
	Evaluating dam safety		X	X	X	
	Evaluating drainage systems		X	X	X	
Sea level rise / Coastal floods	Land protection barriers			X	X	
	Monitoring of SLR, coastal climate and the erosion of coastal zone			X	X	
Droughts / Impairment of water balance (groundwater level)	Restrictions on water use			X		X
	Water conservation		X	X	X	
	Water quality protection		X	X	X	
	Reconsidering land use management			X	X	
	Responsible water use	X			X	
	Infrastructural measures (e.g. sufficient storage of water in impounding reservoirs)			X	X	
Moving on ice becomes risky	Information of the public			X	X	X
Nutrient leach into water reservoirs	Reduction of fertilisers in agriculture		X		X	
	Monitoring measures and reconsidering fertilisation legislations			X	X	

5.3.4. *Energy*

In the Finnish energy sector, we can find different types of ownership, ranging from state-owned to private power production and distribution companies.

As Ruostetsaari (2009) explains, the Finnish energy policy is characterised by features which are special in international comparison. The primary fuel supply is quite diversified[29], the country is highly-energy intensive[30], and despite the mixture of its energy sources, the country is relatively dependent on foreign energy supplies.

Physical impacts

As a consequence from climate warming the need for heating energy in the winter could decrease (some 10% until 2050; Venäläinen 2004) and the need for cooling energy will probably increase in summer. The net effect is expected to be negative in the range of 2-3% and thus indicating a lower net demand for energy in Finland (Tammelin et al. 2002 and Kuusisto et al. 1996, both in Finnish, cited by Kirkinen et al. 2005)

The reliability of energy supply will be critical in view of power plants, transmission and distribution. Particularly affected is the electricity network business with a likely increase in number of network faults due to erosion, variable temperature, wind and precipitation. Underground cables offer the best reliability for improved distribution, but costs of underground cables are about twice as much compared to conventional, above-ground cables. Additional problems through relatively hard bedrock could further increase absolute and relative costs of underground network infrastructure. Additionally, a decreased lifetime of network components would lead to higher depreciations of corporative or public infrastructure (e.g. higher precipitation causes corrosion at steel constructions).

The security of supply during peak load periods will not be affected by climate change. Because in Finland, peak loads are observable during very cold days and these events are expected to occur less often, the reliability during peak loads is not considered to be a serious concern. However, many impacts on the energy system depend on extreme weather conditions, which are very difficult to predict.

Despite expected higher rainfall in the future, the NAS (NAS 2005) does not predict hydropower to increase substantially. This can be explained by local variation and the need for water diversion. For a potential maximum exploitation of hydropower potential, investments in new power plants and turbines have to be made.

Economic Impacts

The study of Martikainen et al. (2007) explores very extensively the impacts of climate change on the electricity network design and construction in Finland. Beside the costs for repairing networks after extreme weather events, also the costs for failures and further climate-induced costs are accounted for. Depending on the specific site where the damage occurs and the damage scenario, the additional costs for electricity transmission networks are expected to rise from 1 to 12 %.

In December 2004, the so called "Rafael-storm" caused damage costs of about 5 million € to Fortum Distribution, an energy company which shares by over 50% belong to the Finnish state. Additionally, the sum of compensation paid to consumers was another 1.5 million €

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[29] The primary fuel supply in Finland is a mixture of different energy sources: Oil (34%), biomass (21%), nuclear power (17%), coal (16%), natural gas (11%) and hydro power (4%) – (figures of 2008, OECD 2009).

[30] In Finland the total primary energy consumption per capita was about 65% higher than in the European Union average (according to 2001 statistics) and about 39% higher than the OECD average (IAEA 2007).

(FINADAPT 2007), contributing to some potential fiscal burden in the case of state-owned energy companies.

Perrels et al. (2005) calculate the change in net value added as a negative value of 37 million € in 2020 and 73 million € in 2050. However, as explained in chapter 5.4, these costs for producers are gains for consumers if they occur due to energy saving. The overall effect is therefore smaller than the mentioned figures.

Until 2005, no further cost estimation of future adaptation to climate change in the energy infrastructure was made. However, implication on the fiscal side can be explained in two ways analogue to other sectors. First, the direct costs could stem from publicly owned energy infrastructure which is subject to adaptation. The second way is an indirect influence through main economic development which is seriously threatened by interruptions in energy supply. The reliability of energy supply is crucial for the whole economy and could, if not available affect all sectors from industrial production to telecommunication. Thus, a lowered economic activity caused by energy problems is likely to reduce tax income and increase social security payments. For long periods of unreliable energy supply, even macroeconomic productivity could be affected with worse fiscal outcomes.

On the other hand, there might be slight beneficial effects in the budgets of private households by a lower heating energy demand. Eskeland and Mideksa (2009) estimate for Finland a decrease of heating degree days[31] from 4,601 to 3,654, for the year 2100 assuming IPCC scenario A1B. This translates into an estimated electricity demand decrease of 284.1 kWh per capita, which is ca. 4.5% of the current per capita electricity demand. However, the authors emphasise the total net effects in Europe are rather small, and their forecasts of energy demand neglect future technological and behavioural changes, which might play an important role regarding the forecast time horizon of 100 years.

Adaptation in the energy sector

As climatic conditions are changing, the structure of energy production needs to be reconsidered. Renewable energies could potentially gain from climate change in Finland (Clausen 2007). Nevertheless, future conditions for an increased use of wind, hydro and solar energy are not predictable today. For bio energy, it can be assumed that if agricultural and forestry productivity increases, the conditions for producing bio energy could also increase proportionally (Kirkinen et al. 2005).

Generally, one has to consider that the energy sector is very capital intensive and can only slowly adapt to climate change. The long turnover period also implies that investments of today have to consider the climatic conditions of a quite distant future. Facing the uncertainties of long term climate projections, Hallegatte (2008) suggests several criteria to rank possible planned adaptation strategies. He does not explicitly include the energy sector into the analysis, but some of the strategies enlisted in Table 17 can be classified by using the proposed criteria: Firstly, preferred options are identified by the no-regret-characteristic. That means that even in the absence of climate change the strategy would yield benefits, as it is the case for the extension of underground power cables and for the investment in hydropower or

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[31] Heating degree days (HDD) is a measure for the heating energy demand dependant on the daily temperature. HDD is the temperature differences in degrees between the daily temperatures (below a comfort threshold) and a defined comfort threshold, summed up during a year. Cooling degree days (CDD) is the analogue measure for temperatures above the comfort threshold.

bio energy, at least in some cases. The second criterion refers to the reversibility and flexibility of a decision. Here there are only few strategies in the energy sector which fulfil this criterion, most decision are based on long term scenarios and are irreversible to a large extent. Another criterion assesses the synergies with mitigation. Obviously mitigation is an important issue in the energy sector, thus there are indeed some adaptation strategies which are also beneficial in terms of mitigation (e.g. energy mix alteration towards hydro and bio energy). Hallegatte (2008) presents more criteria, like soft strategies, strategies that reduce the decision horizon and the existence of cheap safety margins, but the most relevant criteria for the energy sector are presented above.

Table 17: Specific impacts and adaptation responses in the energy sector.

Specific Impact	**Adaptation measure**	**Autonomous – Private**		**Planned Adaptation**	**Nature of adaptation**	
		Consumer	**Producer**		**Proactive**	**Reactive**
Increase in precipitation	Investment in additional hydro power		X		X	
Extreme weather events	Extension of underground power cables		X		X	
Changes in wind velocity	Clarification of future changes in wind velocity			X	X	
	Adapt to changing wind velocity		X		X	
Favourable growing conditions for biomass	Increased use of bio energy	X				X
	Expansion of bio energy infrastructure		X			X
Increase in winter temperature	Less heating energy use	X				X
Higher temperatures in summer and winter	Increased use of wind energy as less ice disturbs propeller blades		X			X
	Decreased used of electricity for heating	X				X
General impacts	Research expansion in alternative power generation		X	X	X	
	Provision of information how electricity needs can be reduced		X	X		X
	Increased investments		X		X	

5.3.5. Transport and communication

According to Finland’s NAS (NAS 2005), there are 78,137 km of public roads and 350,000 km of private roads in Finland. The number of private roads being in good condition has dropped from 73% to 27% in the period from 1989 to 1999.

Passenger cars are by far the most popular means of transport in Finland. While 74% of person-kilometres can be accounted for private cars, the share of public transport is only about 16%. The Finnish rail network is the most extensive in Europe, considered as per capita terms. Maritime transports are quite important for Finland’s international trade relations. About 90% of Finland’s exports and 70% of imports are transported by sea (NAS 2005).

Physical impacts

Precipitation appears to be the main factor in describing the impact on the transport sector. Serious damages in the future could be imagined within the road and railway network. Increasing precipitation causes a rise of groundwater levels which negatively influences the service level of roads and track beds. More storm rains increase the erosion of roadside slopes, bridge cones and embankments.

Rising temperatures imply more winter temperatures around 0°C and thus more liquid precipitation in Southern Finland and more snow and ice in Northern Finland. Inundation of roads, rail lines, and airport runways increase with precipitation and extreme weather events like storm, hail, and floods. Snow and icing risks may mean problems to roads, rail traffic, and airports as well. In water traffic an increase in temperatures improves the safety of sea traffic due to thinner ice cover but with less ice coverage storms may become more frequent. Furthermore water traffic will benefit from extended shipping seasons due to reduced ice coverage. An increase in mean temperature may cause thawing of permafrost and thus subsidence of roads, rail beds and bridge support as well as shortening the season of use of frozen ground for transport (ice roads). Also changes in fuel requirement due to an increase in temperatures are expected. More frequent interruptions in road, rail and air traffic are expected due to an increase in extreme weather events. For example the number of overthrown trees on roads and rail lines could increase with storms. Furthermore damages to transport infrastructure like road and rail networks, terminals and docks are expected to increase with an increase in extreme weather events.

Economic impacts

As it is the case in the energy sector, increased occurrence of extreme climate phenomena could lead to damages in communication networks. These may be caused by broken trees or direct damage to communication lines.

The effects on sea traffic are ambiguous. On the one hand one could expect an improvement of sea traffic safety arising by thinner ice cover and shorter ice periods. On the other hand, with less ice, storms may become more frequent resulting in higher waves and piled up pack ice.

In the following, cost estimates based on recent natural disasters or extreme weather events are presented (Saarelainen 2006).

> **Heavy rainstorm, July 2004**
>
> According to the Finnish Meteorological Institute, rainfall was particularly abundant on two days on July 2004, exceeding 100 mm in 48-hour aggregate precipitation at many locations in Central and Northern Finland. These heavy rains caused severe damage to roads. According to the Finnish Road Administration, an estimated cost of up to 2 million € was assessed only for repair works.
>
> This figure only represents direct repair costs and not additional costs caused by disruption of roads and their economic consequences.
>
> **Heavy rainstorm, August 2004**
>
> Heavy rain in Western Finland with more than 100 mm of precipitation fell within one day. The rains caused heavy flooding within the river Vöyrinjoki watershed and damage to buildings and roads. Cost estimates were provided at about 200,000 €.

Sea level rise on the Gulf of Finland coast, January 2005

Strong winds caused a sea level rise up to 1.95 metre and resulted in minor repair costs. Rehabilitation costs were within the budget framework. Influences in the urban areas were more severe (but their costs were not investigated).

Flooding due to rapid snowmelt and storm rainfall, Lapland

Rapid snowmelt and heavy rainfall caused water level rises of about 2 metres in rivers, causing floods on main roads, buildings and infrastructure. Repair and rehabilitation costs were about 890,000 €.

Adaptation in the transport and communication sectors

In Finland, a certain margin for unexpected events is built into annual budgets of the Road Administration, Railway Administration, Sea Transport and Air Traffic. Although sufficient in history, with higher likelihood of unpredictable extreme weather events, more resources are presumably needed in the long run.

Transport infrastructure's life cycle is normally several decades. Therefore, a changing climate needs to be considered quite early by planning new or replacing old infrastructure. Drainage systems supporting roads and airport runways or other paved surfaces need to be assessed if ready to deal with higher rain intensity, and if necessary need to be replaced by more efficient systems. Furthermore bridges are designed to surmount present water flows and have to be modified to deal with higher precipitation intensity. Additional snow in Northern regions leads to a greater need in snow removal winter maintenance, whereas a higher probability for temperature cycling around 0°C in Southern Finland involves more ice control maintenance (Ala-Outinen et al. 2004).

Adaptation options to an increase in heat days and mean temperatures are relocation of section of roads, rail lines, and airport runways built on frozen ground to more stable ground. Also the development and use of new paving material on roads and airport runways is necessary to adapt to thawing surface. Adaptation options to an increase in extreme weather events are the elevation of roads and rail lines and increases in the pumping capacity of tunnels to protect them from inundation. Furthermore building, heightening and strengthening of levees, seawalls and dikes will be necessary to protect roads and rail lines form inundation due to floods and harbours from wave damage and storm surges.

Due to the uncertainty of long-term climate projections and the long decision horizon in investment decisions, here the ranking method of Hallegatte (2008) (see section 5.3.4) can also be adopted for the transport infrastructure decisions, though he did not explicitly mention that sector. However, in the case of private adaptation decisions some of the criteria are not applicable (such as soft strategies or synergies with mitigation).

Regarding public budgets, the economic benefits of climate change in transport accrue mainly to private actors like the transport industry (in water transport), only to a minor degree to public budgets (e.g. in the case of less winter maintenance), whereas the economic damages (in the form of infrastructure damages) have to be borne by the state to a large extent. This imbalance leads to expectedly relatively high economic burden on the public budgets. Here reactive measures are dominant, which suggests an occurrence of a considerable amount of residual damages in the transport sector. The effect is amplified by the high grade of exposure given by the high number of per capita rail network km.

Table 18: Specific impacts and adaptation responses in the transport and communication sectors.

Specific Impact	Adaptation measure	Autonomous – Private		Planned Adaptation	Nature of adaptation	
		Consumer	Producer		Proactive	Reactive
Increased risk of collapse of road and railway infrastructure through intense precipitation and floods	Early warning systems			X	X	
	Elevation of roads and rail lines			X	X	
	Building, heightening and strengthening of levees and dikes			X	X	
	Monitoring and maintaining public road and rail infrastructure quality			X	X	X
	Monitoring and maintaining private road quality		X		X	X
	Reconsidering construction guidelines for road and railway infrastructure			X	X	
Winter Temperatures around 0°C in Southern Finland	Relocation of section of roads, rail lines and runways			X	X	
	Development and use of new pavement material		X	X	X	X
Shortening of ice and snow cover period in Southern Finland	Less winter maintenance for road and rail networks		X	X		X
	Increase of winter traffic on maritime transport ways		X			X
Increased snow intensity in Northern Finland	More winter maintenance for road and rail networks		X	X		X
Potentially increase of pack ice in Baltic sea	Monitoring of the ice conditions in the Baltic Sea		X	X	X	X
Extreme weather events	Upgrading of drainage systems and increases in pumping capacity of tunnels			X	X	
	Protective constructions, more resistant materials for roads, airport, runways and railways			X	X	
Extreme weather conditions with negative effect on communication network	Repairing storm damages of overhead cables		X			X
	More underground communication cables		X		X	

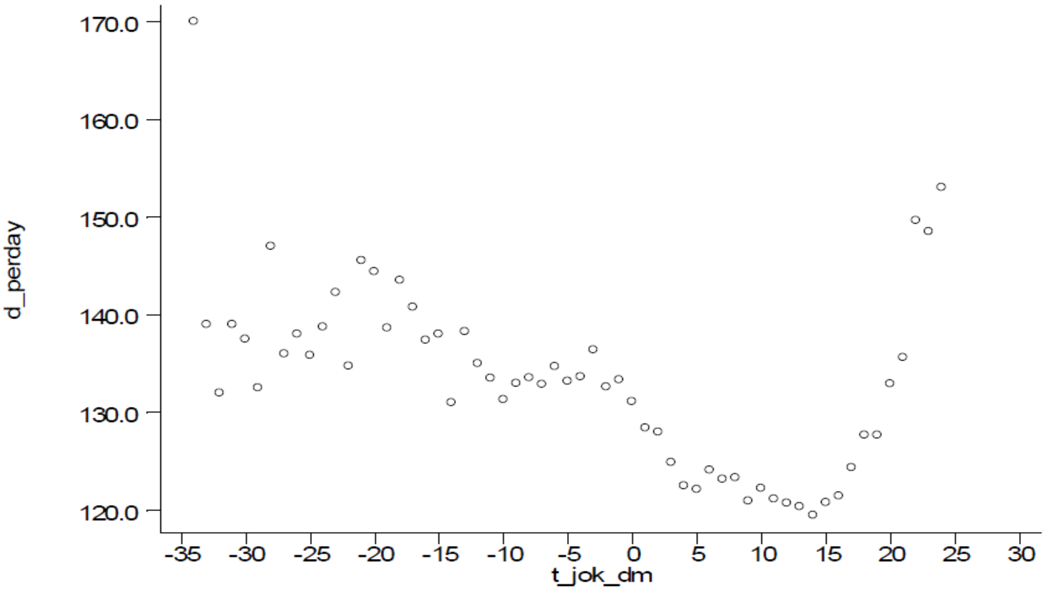
5.3.6. Health

Physical impacts

According to Berner (2005), a discussion of climate change impacts on health must deal with mechanisms rather than attempting to predict health status in some predicted future climate scenario. That is supported by the especially complex functional mechanism through which environmental changes affect human health. The vulnerability of a population depends on factors such as population density, level of economic development, local environmental conditions, pre-existing health status, and the quality and availability of public health care (Woodward et al. 2000). The mechanisms of climate impacts on health are divided into direct impacts, such that directly caused e.g. by temperature, and indirect impacts, e.g. climate induced changes in wildlife and the diseases they share (Hassi and Rytkönen 2005).

The population in Northern countries like Finland is particularly sensitive to heat. Mortality increases clearly in Finland when daily average temperatures remain above +20°C for 1-2 weeks. The optimum thermal threshold for minimum mortality is +14°C in Finland as can be seen from Figure 26:

Figure 26: Daily mortality in Finland (d-perday) in relation to daily mean temperature at Jokioinen, Southern Finland (d_jok_dm) during 1971-1997. Source: Hassi and Rytkönen 2005.



However, the effect of heat on mortality has decreased in the last decades but is particularly relevant for elderly. Excess winter mortality is a well known phenomenon in Finland, where 3,500 extra deaths occur during the winter season. Other health problems than mortality related to cold weather are performance limitations, illnesses and injuries that occur during cold periods in Finland. Together, this leads to a higher consultation load of the health care system and higher cost to the public health care system.

However, there is quite high confidence that the predicted climate warming during the forthcoming decades will not pose particular new risks for the population of Finland. Heat-related mortality and morbidity will be increased slightly, but simultaneously wintertime mortality and morbidity will decrease under a warming environmental temperature (Hassi et al. 2005). Human organisms are able to adapt to these slow climate changes ("acclimatisation"). This can also be deduced from the observation that Southern Europeans show a much lower mortality at high temperatures than Finnish people (Keatinge et al. 2000). There are also considerable adaptation capacities by technical measures which are highly probable to be realised. In contrast to slow temperature developments, extreme weather events and sudden temperature changes within few days pose much more serious challenges to the human organism. Consequently, the ACIA (Arctic Climate Impact Assessment 2005) states that especially extreme events will cause most of the additional burden of climate related adverse health effects.

Economic impacts

For many of the potential health impacts of climate change, a causal link is hard to establish. Moreover, technology in the health care sector is almost impossible to predict. Therefore quantitative results for impacts in the health sector in Finland are hard to assess and not available yet. One reason might be that the publicly funded ISTO research programme (see section 5.1) does not include the health sector due to a lack of funds.

Adaptation in the health sector

Sufficient availability of public health infrastructure, which includes also early-warning systems and public education programmes could substantially decrease potential risk of climate-change-induced adverse health effects. Awareness-raising through providing information on the risks associated with climate-change-induced adverse health effects is one important factor which could substantially decrease health impacts. Sufficient research into the area of temperature-sensitive infectious diseases is another effective adaptation measure. Most reactive measures and strategies to cope with residual damages cannot be described as adaptation measures since those strategies are existent already without climate change. These are conventional treatment of diseases and health insurance.

Table 19: Specific impacts and adaptation responses in the health sector.

Specific Impact	Adaptation measure	Autonomous - Private		Planned Adaptation	Nature of adaptation	
		Consumer	Producer		Proactive	Reactive
Unknown impact of climate change on health	Provision of sufficient financial resources for research			X	X	
	Development of disease early warning systems			X	X	
Possible increase of infectious diseases	Research and development for treatment of newly immigrated and spread diseases		X	X	X	X
	Awareness raising through public education programmes			X	X	
Heat waves	Increased air conditioning	X	X			X
	Ensuring air conditioning and sufficient ventilation in retirement homes and hospitals			X		X
	Urban planning with consideration of the urban heat island effect			X	X	
Possible increase of adverse health effects	Securing availability of health care – sufficient public health care infrastructure			X	X	

5.4. Macroeconomic costs of climate change

The FINADAPT project offers a basic, preliminary study of economic impacts generated by climate change. Perrels et al. (2005) present an approach to first-order costs[32] and benefits of climate change for Finland, accounting for sector specific impact results. They add the assumption that effects on the economy can be "imported" through world markets and economic changes in export countries. The population development is assumed to be not affected by climate change but start to decline after 2030. As singular events of weather extremes are hard to assess, they have mainly been kept outside the assessment with some exceptions. The demographic and economic trends used for the study are described in Table 10 on page 76. The authors use the A1 emission scenario, as quantitative information in the analyzed sectors is mostly available for the A1 scenario. The quantitative impact results are given for each sector. Below, an overview of expected costs and benefits is provided in Table 20. Economic costs and benefits are expressed in prices at 2000-levels and in comparison to the baseline development without climate change.

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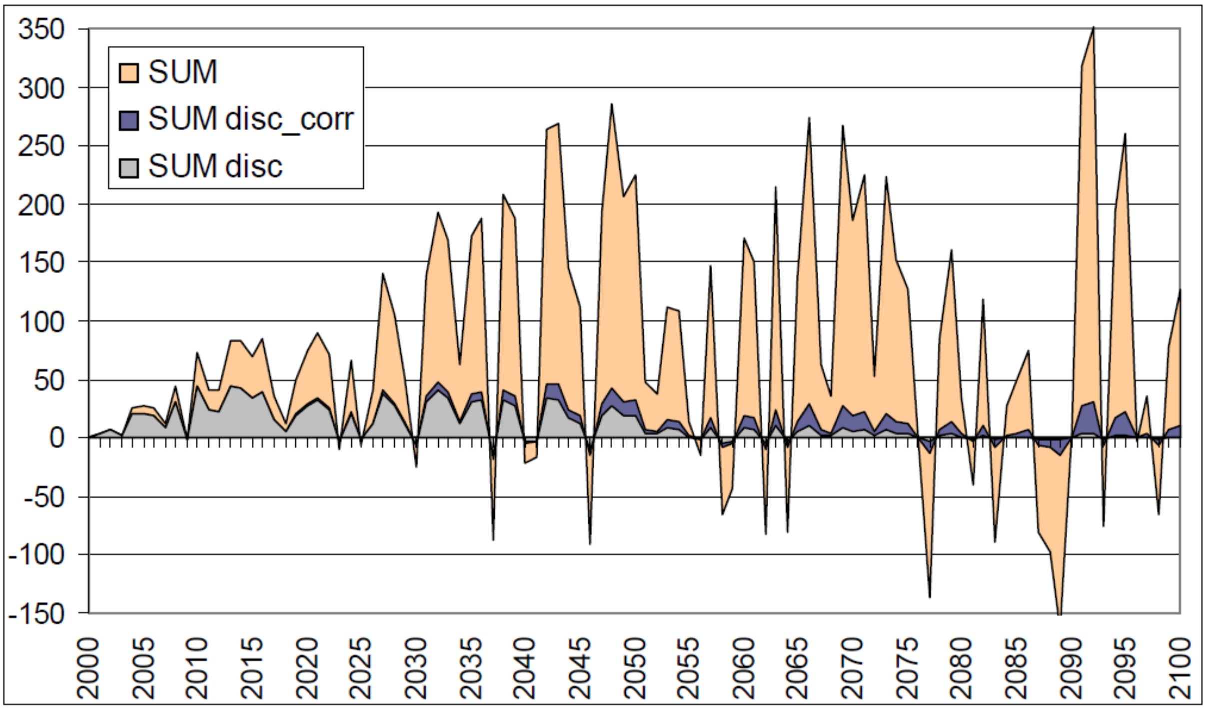
[32] First-order costs are explained as effects on production costs or damages to capital and sales stock. The (not-analysed) spill over effects to the rest of the economy depend on how these changes in first order costs are absorbed in product and factor prices.

Table 20: Overview of impacts per sector in Finland for the A1 scenario. Source: Perrels et al. 2005.

Sectors	Changes in net value added (million €)	
	2020	2050
Agriculture	60	100
Forestry	75	150
Energy	-37	-73
Tourism (hotels, leisure facilities, etc.)	107	107
Hydrology	-22	-32
Transport	-?	-?
Real estate	-?	-?
Banking & Insurance	-/+?	-/+?
Other services	-/+?	-/+?
Imports	-/+?	-/+?
Exports	-?	-?
Consumption induced production	-60	-80
TOTAL	135	172
% of GDP	0.06	0.04
TOTAL excl. tourism	22	65
% of GDP	0.01	0.02

For the sectors which were not quantitatively assessed, substantial impacts of more than a few million € per year are not expected (Perrels et al. 2005). As the authors emphasise, the calculated average costs should be considered with caution for several reasons. The first problem is that uncertainty about various physical and economic effects, particularly at regional level, is still high. Furthermore, an average figure doesn't necessarily represent the different impact magnitudes, varying from year to year. Although the expected average effect on economic growth can be considered as low, extreme events with impacts above the average in some years can still severely affect economic development. Figure 27 gives a picture how important these temporary impacts may become. At the same time it shows the importance of the discount rate that is assumed.

Figure 27: Annual effects of climate change on some sectors of the Finnish economy in million €.

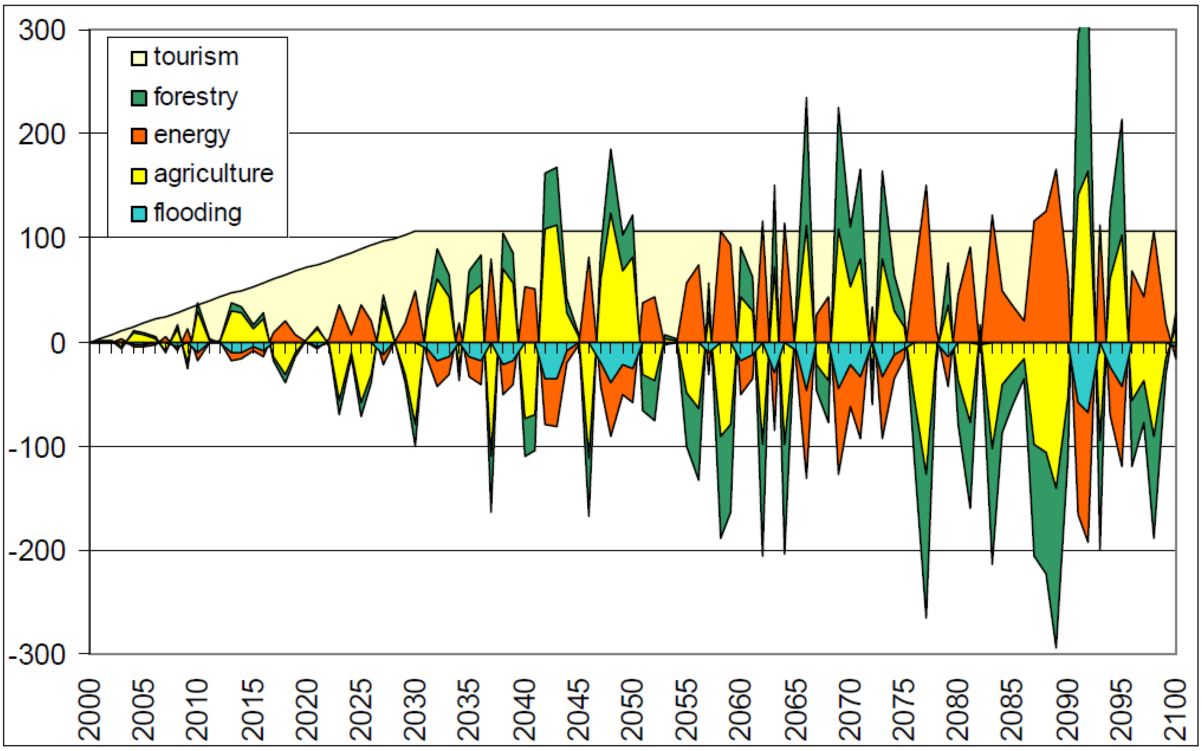


"SUM" depicts the simple value of the effects which occur in the respective year. "SUM disc" is calculated by a traditional discounting method and thereby accounts for the low importance of events in the far future. "SUM disc_corr" uses a crude correction method ensuring that the discount rate increases over time and events in the far future do not become totally irrelevant. Source: Perrels et al. 2005.

From Figure 27 it should become clear, that even if the average effect of climate change in Finland will be slightly positive (see Table 20) annual effects on all analysed sectors can become strongly negative. In particular, climate change can pose a large burden of the economy, if two years with adverse effects follow on each other. For private actors this might cause severe financial and liquidity difficulties. However for the government the average effect is more relevant, since fiscal budgets are generally more capable to smooth the expenses over time.

Figure 28 sheds a light on the sectoral distribution of climate change impacts. It becomes clear that the overall net benefit is composed of many strongly positive and strongly negative gross effects, which will challenge different sectors in different years. As one cannot assume a sufficiently functioning redistribution system between sectors and periods which by theory would be able to smooth the losses, a net perspective clearly falls short in analysing real economic impacts of climate change.

Figure 28: Annual effects of climate change on some sectors of the Finnish economy in million €. Source: Perrels et al. 2005.



Moreover, the estimated costs do not include induced effects on other sectors and therefore omit indirect effects on the economy. In this regard the authors emphasise the potential adverse effects from international trade. Climate change is expected to reduce the available income in many countries in the world, including trade partners of Finland. A quantitative analysis for Finland is still missing, but Bräuer et al. (2009) conclude in their study for Germany, that these effects are far from negligible, but rather the largest adverse effects expected in Germany for 2100. As Finland has an exports share of GDP comparable to Germany[33], one can assume high, unpredicted costs by climate change, which in part will also influence the government budget through indirect income effects.

Perrels et al. (2005) come to the conclusion, when comparing the estimated average effects with Finland's GDP that the overall nationwide effects are very modest and not substantially different from zero, keeping in mind the problems discussed above.

However, regarding public finance effects, results may vary from those results referring to the whole economy since economic burdens are mainly located in areas with high state activity whereas benefits are mostly expected in privately dominated sectors.

Another study on macroeconomic impacts of climate change is made by Maddison (Maddison 2003) for 88 different countries. In this study the costs are estimated which have to be borne to maintain the current happiness facing a 2.5°C global warming. Methodologically, the study is based upon self-reported happiness and is therefore sensitive to subjective over- or understatement, amongst other limitations. For Finland the author derives a change in

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[33] According to the World Bank, the share of exports of goods and services of the GDP in 2007 was 47% in Germany, and 45% in Finland. For comparison, the same indicator for France was 27% and for the UK 26%.

constant utility cost of living indices (i.e. the additional costs which have to be borne to maintain the current utility under climate change) of -2.1%. That is, Finnish households would have to spend less to maintain their living standard under climate change. However, methods basing on self-reported happiness come along with large uncertainties with regard to the objective impacts. Besides, Maddison only considers impacts on the costs of households, without impacts on the industry.

5.5. The fiscal effects of adaptation

As already mentioned in the case study for Germany (see section 4.6), the current status of quantitative research does not allow a comprehensive analysis of adaptation costs in the different economic sectors. Nevertheless, the findings of the previous sections can be summarised in presenting certain tendencies. Thereby it can be said where high public costs can be expected, and in which sectors mainly private actors will have to take the burden.

The latter is the case in the agriculture sector. Here great parts of the presented adaptation measures are of private nature. If government activity is needed, then it comes at relatively low costs. That is because the public planner steps in mainly as a regulator (keywords are land tenure and insurance regulation), rather than a major investor. However, if insurance markets grow and possible premium subsidies are guaranteed over a long period, the fiscal burden may also rise in that sector.

In contrast, the forest sector may bring slight positive fiscal effects, due to a productivity increase and high public shares in the ownership structure of Finnish forests.

Adaptation to climate impacts in the water sector may become costlier to the Finnish government, since flood protection is a public good which often necessitates government action; so the shares of the public budgets in total adaptation expenditure is higher than in the other sectors. However, total fiscal costs are relatively low, compared to other European countries. One reason is the physical preconditions which ease an effective coastal protection; another is the regulation of coastal protection, which – to a limited degree – enforces also private engagement in coastal protection (see section 0).

As for the energy sector, fiscal effects mainly accrue due to public shares in energy companies. These effects are expected to be negative, but according to experiences from past extreme weather events they are not expected to pose a major challenge to the Finnish budgets. With regard to pure private and public investment (without taking the public shares in energy companies into account), adaptation in the energy sector is almost completely a private issue.

This is different in the transport sector. Building and maintenance of road networks are major public tasks. According the findings in section 5.3.5, there will be significant extra costs due to adaptation to a changing climate, whereas the benefits of climate change will accrue mainly to the private actors. The high uncertainty of future climate damages and costs of adaptation possibly makes this sector one of the most relevant in terms of adaptation costs in Finland.

Finally, the health sector shows a clear tendency towards public interventions, but none of them is expected to result in very high fiscal pressure. Most measures are not very costly, compared to other activities in other sectors.

As a conclusion one can state that the direct fiscal effects from adaptation in the presented sectors in Finland may result in fiscal pressure, which is however not expected to be very high, at least in comparison to other European countries. Exact or even rudimentary quantitative results are not yet available in the literature. The same is the case for indirect fiscal effects, e.g. resulting from decreasing tax revenues due to forced private investment in adaptation. As described in section 4.6 for the German case, that is a major drawback since indirect effects can be significantly higher than the direct effects from climate change.

6. Case study III: Climate change impacts and adaptation in Italy

6.1. National Adaptation Strategy

Italy is located in the Mediterranean climate zone with the Alps in the North and surrounded by the Adriatic, Ionian, Mediterranean and the Tyrrhenian Sea in the South. In respect of climate change impacts the Mediterranean area is considered as one of the most vulnerable regions in the world. This is intensified by its population density, the concentration of economic activities in coastal zones, and for its climatic borderline equilibrium between warm and continental macroclimate in the South and colder, more maritime macroclimate in the North (Carraro and Sgobbi 2008).

While the awareness of climate change as a drastic challenge for the future is generally existent, it applies mostly to the understanding of policy action regarding mitigation strategies. Specifically, no official adaptation strategy for Italy has been developed yet. In the light of potential future threats through climate change in the Mediterranean, the lack of an official adaptation guideline is quite surprising.

Identifying the knowledge gap, the 2007 National Climate Change Conference in Rome, promoted by the Italian Ministry of Environment and Protection of Land and Sea, focused on adaptation and intended to start the process of developing a national adaptation strategy in Italy. Nonetheless, no release date of an adaptation strategy has been announced yet. In comparison to other European countries like Germany or Finland, there is no regional climate projection specifically available for Italy. Thus, this bottom up case study is necessarily based upon a limited number of local and national studies.

Although there is hitherto no systematic national adaptation plan to climate change impacts, a few projects with a sectoral or regional focus are ongoing. The Italian Ministry for the Environment and Territory (IMEL) will establish a National Action Plan and build a Committee to address the problem of desertification. Furthermore a National Plan for irrigation will be implemented, where extreme weather events are taken into consideration. A Rural Development Plan will be set up which includes specific measures for water resource protection with respect to the “improvement of agricultural sector and forestry competitiveness” and “environmental and rural areas improvement”. The objective of the project SAL.VE is to safeguard Venice and its lagoon. Besides the defence from high waves and sea storms, it includes also the protection of the environment within this area.

Apart from the ongoing adaptation actions, there is one project called CLIMAGRI (climate change and agriculture), which ran from 2001 to 2004. The subject was “to improve the knowledge of linkages between agriculture and climate change” (AGRI 2006). The project focussed “on climate change impacts, but with a view to support implementation of response measures and draw recommendations for adaptation” (AGRI 2006). Sub-projects were (1.) climatic analysis and future scenarios, (2.) the Italian agriculture and climate change, (3.) drought, desertification and water resources management, and (4.) data dissemination and communication.

In addition to these projects, Italy is involved in the development of regional and cross-border plans and associations: The Mediterranean Adaptation Plan under the United Nations Environment Programme (UNEP) and the Action Plan on Climate Change within the Alpine Convention.

6.2. Climate and its trend in Italy

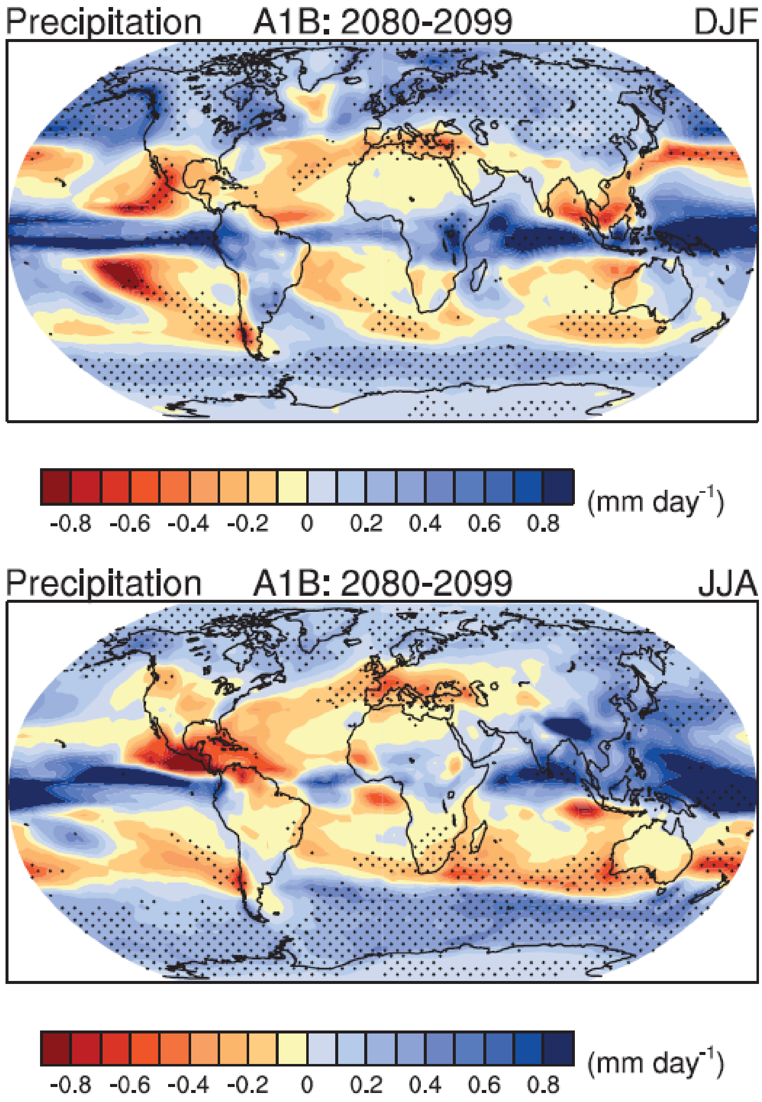
6.2.1. General overview

As a Southern European country, Italy is placed in a transition zone between the arid climate of North Africa and the temperate and rainier climate of central Europe with the Alps as he dividing line. The mid-latitude as well as tropical processes influence local weather conditions. The climate of the Mediterranean can be described as mild and wet during the winter and hot and dry during the summer (Giorgi and Lionello 2008).

The Mediterranean is one of the regions where the multiple climate projection models used by the IPCC Fourth Assessment report come to reasonably comparable results, even given the quite uncertain projection of precipitation changes, as

Figure 29 illustrates.

Figure 29: Multi-model mean changes in precipitation (mm day–1, middle) for boreal winter (DJF, top) and summer (JJA, bottom).



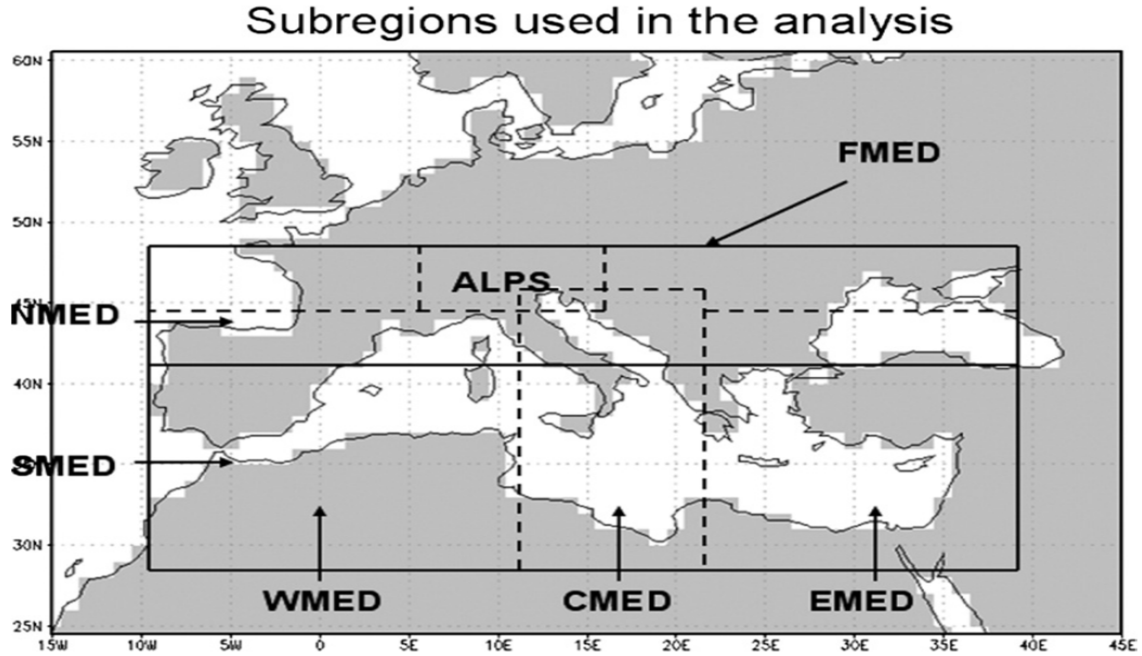
Changes are given for the IPCC A1B scenario, for the period 2080/2099 in comparison to 1980/1999. Stippling denotes areas where the magnitude of the multi-model ensemble mean exceeds the inter-model standard deviation, i.e. here the results of the multitude of models show a reasonable correlation. Source: IPCC 2007.

Despite being considered one of the most prominent “hot-spots” in future climate change, surprisingly few publications on climate change projections for the Mediterranean area are available. As Giorgi and Lionello (2008, p. 91) admit “despite the importance of this region within the global change context, assessments of climate change projections over the Mediterranean region are relatively sparse”. As Carraro and Sgobbi (2008, p.3) put it “we still lack accurate projections about the likely physical impacts of climate change, in particular at the national and regional level. Specific efforts for Italy have not yet been made.”

As no regional climate projection for Italy has been conducted so far for analysing possible impacts of climate change, we have to look at broader regional climate projections for the Mediterranean zone. A review of climate change projections over the Mediterranean area, based on the latest sets of global and regional climate model simulations, can be taken from Giorgi and Lionello (2008). The assessment provides projections for the whole Mediterranean as well as for a number of sub-regions (

Figure 30). Accordingly, essential parts of Italy can be classified in the Central Mediterranean region (CMED)[34] and the Alps region (ALPS)[35]. If there is no nation-specific data or literature available, we therefore refer to studies covering the Mediterranean or Alpine regions.

Figure 30: Subregions of the Mediterranean. Source: Giorgi and Lionello 2008.



6.2.2. Changes in detail

In this chapter, all projections and estimates underlie the different stages of uncertainty as presented in the case study for Germany, section 4.3. As for the emission scenarios, mostly the scenario A1B is used to demonstrate a medium change in climate. The downscaling of global climate models is not as precise as in the cases of Germany and Finland, as not many downscaling approaches especially for Italy or the Mediterranean exist by now. Nevertheless, it is reasonable to conclude different climate impacts for Northern and Southern Italy (or the ALPS region and the CMED region in Figure 30).

6.2.2.1. Changes in temperature

The Mediterranean region can be expected to experience higher temperatures in the future (IPCC 2007). The MGME[36] average results in the A1B scenario for the four seasons are displayed in figure 31. As can be seen, in winter the maximum warming magnitudes can be found in Northern Italy, whereas in spring and summer the south will get most of the high increase and in autumn all parts of Italy will be affected. Near-term projections are also only available for the whole Mediterranean region, telling us a projected increase in temperatures of 0.75-1.5 °C by 2020, 1.5-2°C by 2040 and 2-3 °C by 2060 depending on the season.

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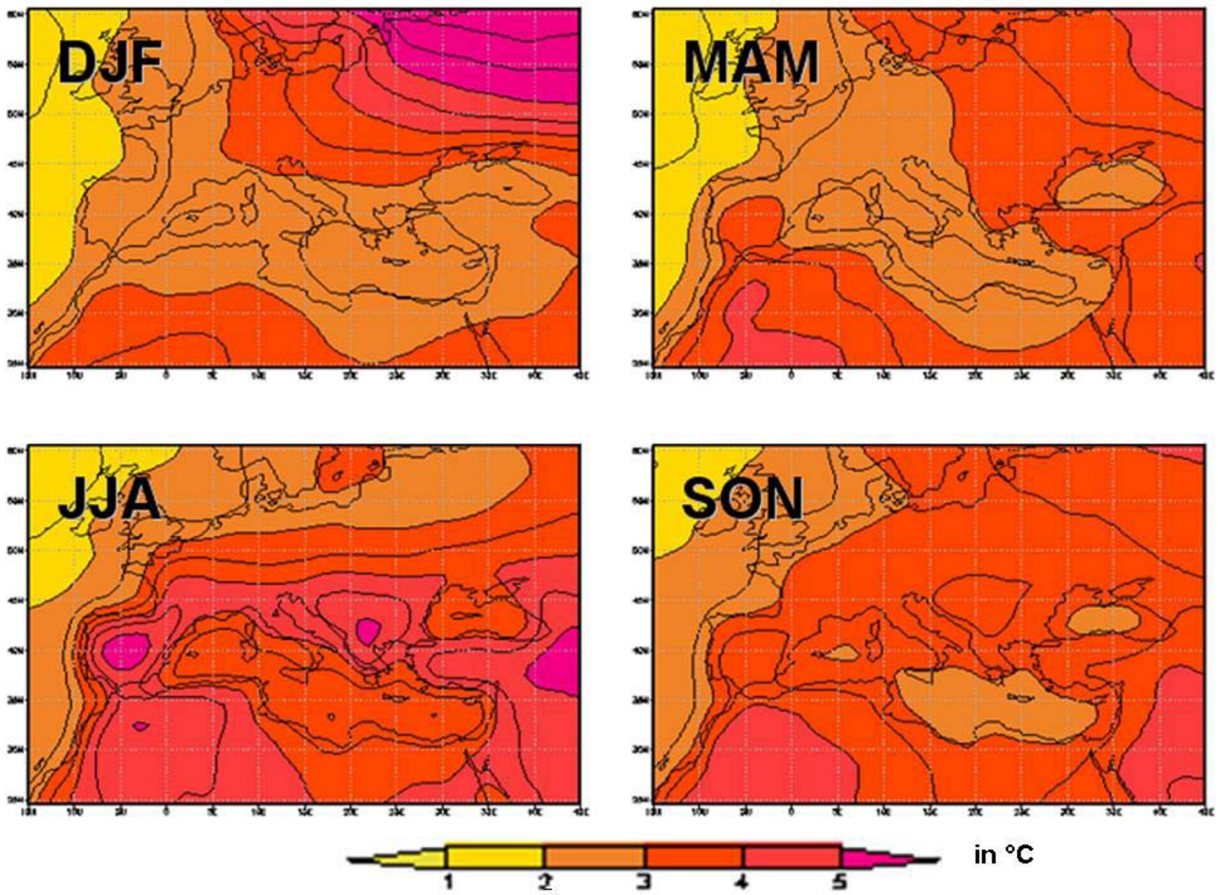
[34] CMED is geographically defined as 28–46 N and 10.5-20.5 E

[35] ALPS is geographically defined as 44-48 N and 5.5-15.5 E

[36] MGME stands for Multi Global Model Ensemble. Model ensembles resemble multiple different global climate models in order to show a more comprehensive and reliable picture of future climate change than only one single model. See also section 4.3.

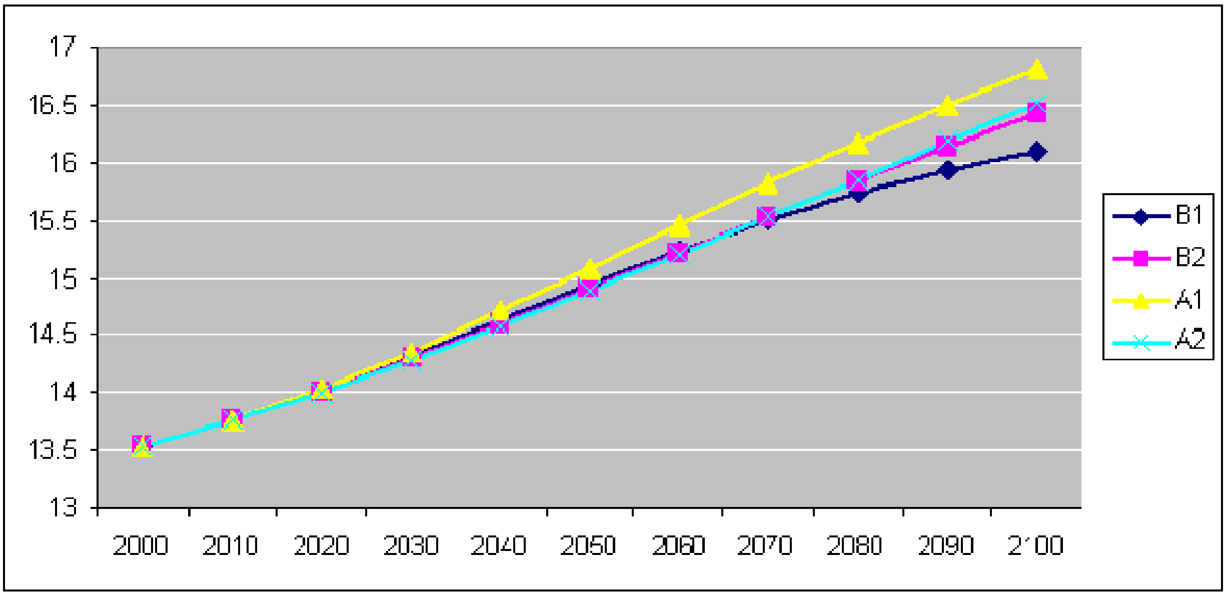
Figure 31: Average temperature change in the Mediterranean in °C; 2071/2100 to the baseline period 1961/1990.



DJF stands for December, January, and February; MAM, JJA, and SON for the other months accordingly. Source: Giorgi and Lionello 2008.

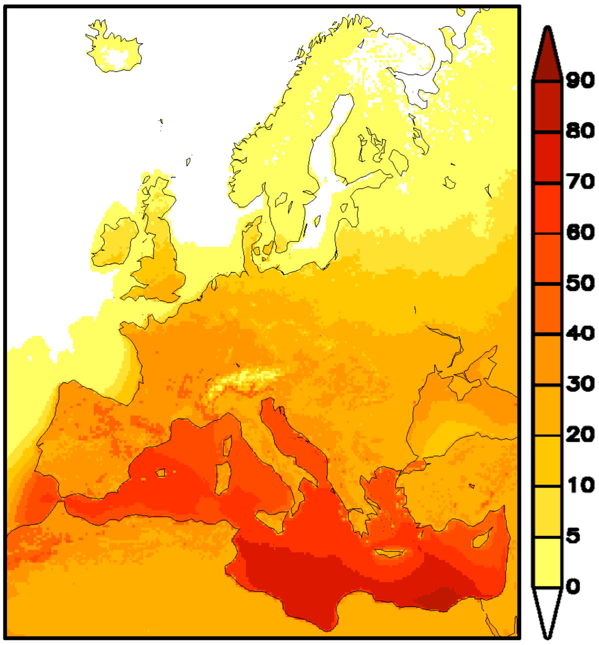
In a sub-regional projection for the period 2071-2100, the CMED region is expected to heat up between 3 and 4.5 degrees Celsius, with the temperature increase largest in summer. The ALPS region is projected to experience a comparable increase in mean temperatures. To give an impression of future climate conditions, the average temperature levels for Italy are shown in Figure 32.

Figure 32: Projected average temperature levels (°C) for Italy 2000-2100 in four different IPCC scenarios. Source: Bigano and Bosello 2007.



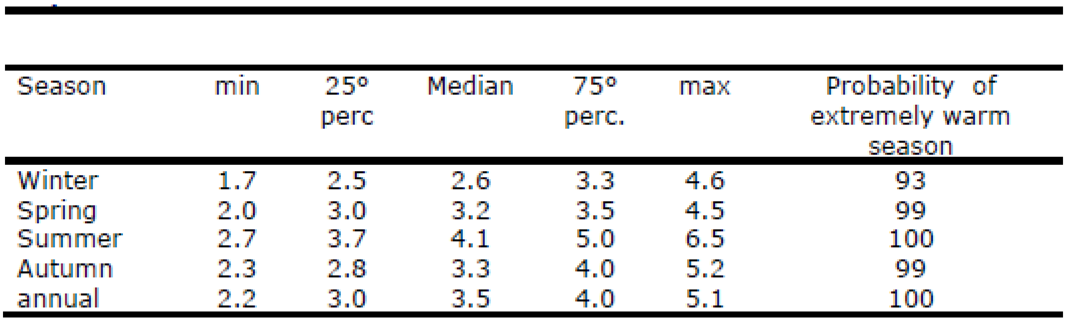
Regarding extreme weather events, climate projections rather univocally predict an increase of summer heat days in the Mediterranean. Figure 33 illustrates the increase in number of days with maximal temperatures above 25°C, calculated by the dynamic regional climate model CLM.

Figure 33: Change in number of summer days (maximum day temperature > 25°C) per year, projection of dynamic regional climate model CLM based upon IPCC scenario A1B, comparing 2051/2080 with 1961/1990.



The estimations of average temperatures increase for South Europe are shown in Table 21, where the minimum, the maximum, the median, the 25th and the 75th percentile of temperature variations foreseen by 21 models in the A1B scenario are reported.

Table 21: Average temperature variation (°C) estimated in 21 models from 1980-1999 to 2080-2099 and probability of "extremely warm season" in the period 2080-2099.



Season	min	25° perc	Median	75° perc.	max	Probability of extremely warm season
Winter	1.7	2.5	2.6	3.3	4.6	93
Spring	2.0	3.0	3.2	3.5	4.5	99
Summer	2.7	3.7	4.1	5.0	6.5	100
Autumn	2.3	2.8	3.3	4.0	5.2	99
annual	2.2	3.0	3.5	4.0	5.1	100

The probability of an "extremely warm season" is calculated by extracting the warmest summer from the simulations in the control period 1980-1999, which is then used as reference value for each forecasting model. The fraction of summers in which the temperatures exceed this reference value in the period 2080-2099 finally represents the probability of an "extremely warm season". Scenario A1B, South Europe. Source: Ministry for the Environment, Land and Sea 2007.

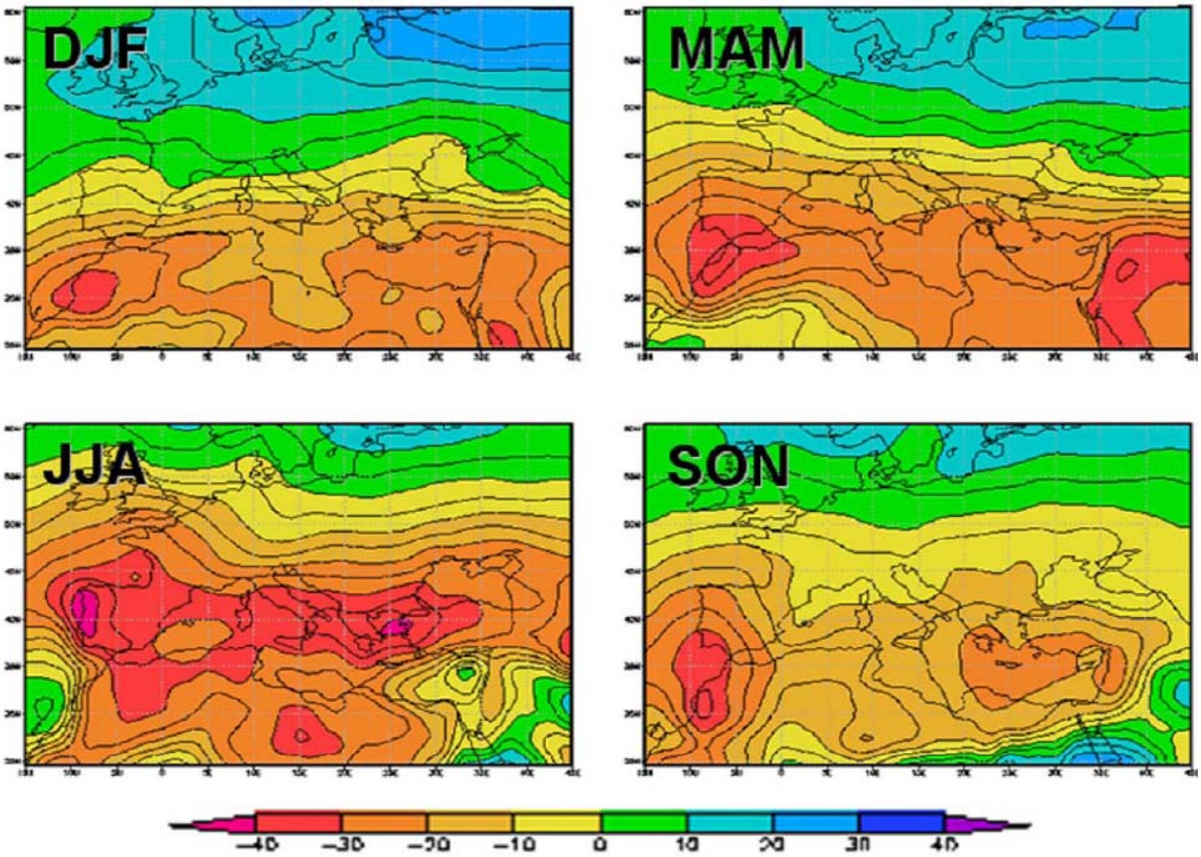
Following these data, all the models concur in forecasting warmer summers than the warmest summer of the period 1980-1999 for the end of the century, in South Europe and assuming scenario A1B.

6.2.2.2. Changes in precipitation and windiness

The Mediterranean region can be associated with a general reduction in precipitation, in contrast to Northern Europe where a pattern of increasing precipitation is expected (Giorgi and Lionello 2008). Near-term projections provide some negative values for precipitation changes in the Mediterranean region of 2-7% by 2020, 4-10% by 2040 and 5-23% by 2060 depending on the season. The highest decrease in rainfall can be expected in the summer, the lowest in the winter.

According to sub-regional projections for the period 2071/2100, the CMED region can be expected to experience a 6-27% decrease in mean precipitation. Contrary to this development, the ALPS region could face a broad range of changes, from an increase of over 5% in the winter to a 17% decrease in summer. Seasonal precipitation changes, assuming the IPCC scenario A1B and based on a multitude of climate projection models, are illustrated in Figure 34.

Figure 34: Average precipitation change in the Mediterranean in % of current precipitation; 2071/2100 to the baseline period 1961/1990. Source: Giorgi and Lionello 2008.



As for the variation between climate models, Table 22 depicts the variations of precipitation changes shown by 21 models, assuming IPCC scenario A1B. Compared to temperature estimates, the variation is higher but the predictions still show a clear tendency towards less precipitation and a higher probability for extremely dry seasons than for extremely rainy seasons.

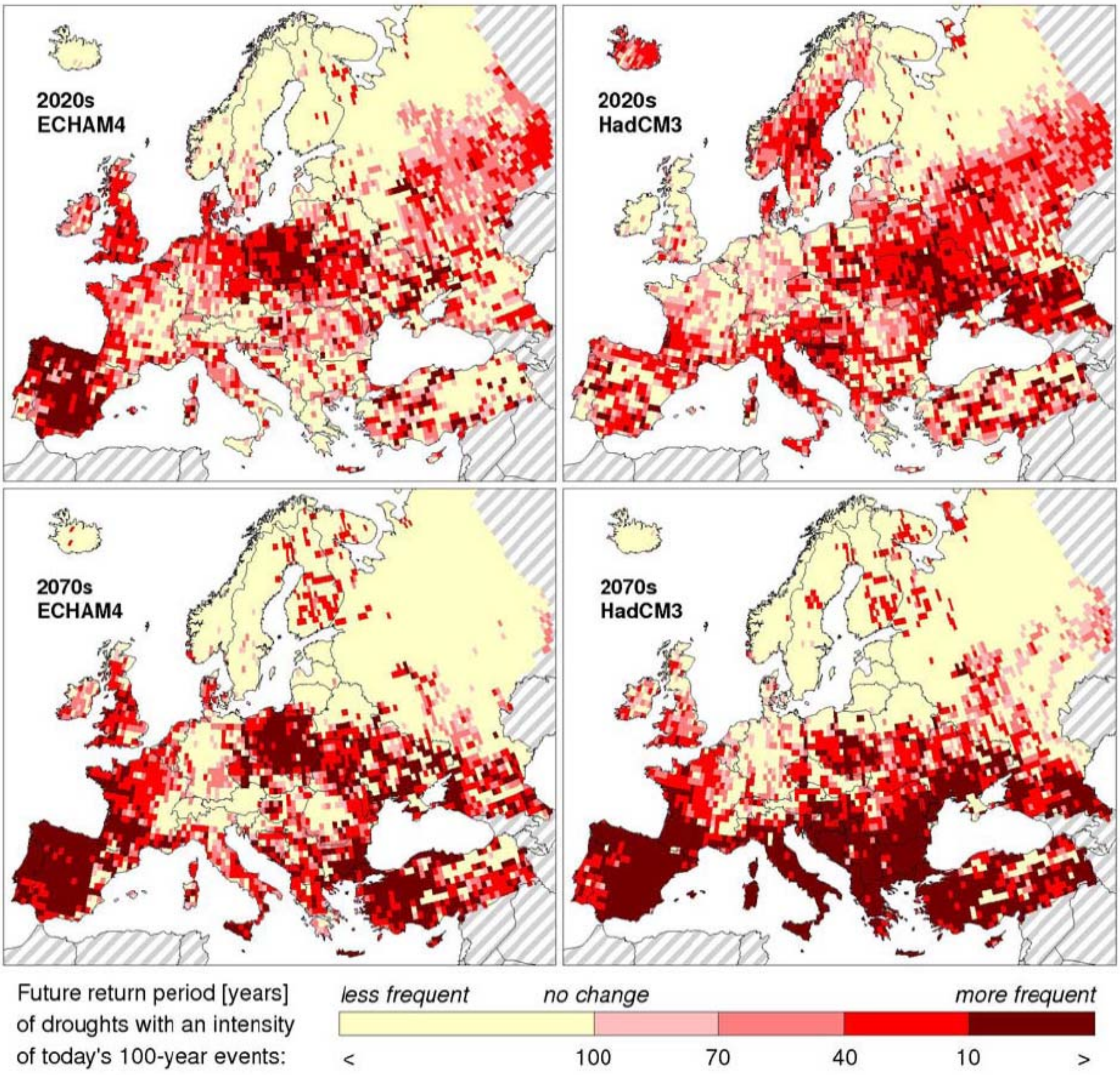
Table 22: Percent variation of cumulated rainfalls foreseen by 21 models from 1980-1999 to 2080-2099 and probability of "extremely rainy season" and "extremely dry season" in the period 2080-2099.

Season	min	25° perc	median	75° perc.	Max.	probability of extremely rainy season	probability of extremely dry season
Winter	-16	-10	-6	-1	6	3	12
Spring	-24	-17	-16	-8	-2	1	28
Summer	-53	-35	-24	-14	-3	1	41
Autumn	-29	-15	-12	-9	-2	1	21
annual	-27	-16	-12	-9	-4	0	45

Extreme seasons are measured analogue to Table 21. A1B Scenario, South Europe.
Source: Ministry for the Environment, Land and Sea 2007.

The projection of extreme drought events is consistent with the mean precipitation projections. Figure 35 depicts the estimated change of such droughts with a current return period of 100 years and thereby shows the expected frequency of these extreme events in the 2020s and 2070s. It illustrates the estimates of two different Global Climate Models and thereby accounts for the severe uncertainty which is always inherent in the choice of climate models. Nevertheless, both models predict a significant rise in the probability of extreme drought events for Central and South Italy.

Figure 35: Future return periods of droughts with an intensity of today's 1/100-events, based on two different Global Circulation Models.



If an area is coloured in red, it means a drought which today occurs expectedly every 100 years, in future occurs probably every 10-40 years. Source: Hattermann und Huang 2008.

Regarding windiness, as the IPCC 4th Assessment report for Europe (IPCC 2007) explains, there is generally low confidence in future changes of wind speed in Europe. A possible northward shift in cyclone activity could reduce windiness in the Mediterranean Sea (Lionello et al. 2002). Nonetheless, there is no agreement on whether the total number of cyclones will actually increase or decrease (Lionello et al. 2002; Pinto et al. 2006).

6.2.2.3. Snow conditions in the Italian Alps

The Alps have a fragile ecosystem, which is vulnerable to any changes of temperature and therefore to the climate change. Higher temperatures are leading to a significant reduction in snow cover, especially leading to a shortening of the snow cover period in spring. An estimated 1°C rise in temperature is projected to reduce the snow cover duration by up to several weeks (Hantel et al. 2000)[37], whereas a 4°C increase could reduce the snow amount up to 90% at 1000 m and 30-40% at 3,000 m altitude (Beniston 2003)[38].

Regarding the existence of glaciers, it can be concluded that most of the Alpine glaciers will disappear at the end of the century (Haeberli and Burn 2002). The Alps could lose up to 80% of their glacier cover by the end of this century, if summer air temperatures increase by 3°C. Further, if temperatures continue to warm by 5°C, the Alps would become almost completely ice-free by 2100 (Zemp et al. 2006).

The increasing temperature has far reaching consequences. The melting of the glaciers and permafrost along with precipitation extremes alter the hydro-geological cycle in the mountains. This will have repercussions on both the water balance of rain collecting basins and the stability of mountain slopes. Moreover migration of ecosystems towards higher altitudes may also lead to changes in biodiversity and many Alpine species are in peril (EEA Report No 8/2009).

6.3. Impact assessment and adaptation strategies in critical fields

Generally, vulnerability is determined by several factors such as environmental, social and economic criteria. The more advanced the development level of a society is, the better is its capacity to cope with environmental changes. Concerning the case of Italy, high social and economic inequalities across Italian regions can cause different degrees of vulnerability to climate change (Gambarelli and Goria 2004). In 2000, 62.7% of poor households were located in Southern Italy whereas 15.3% lived in the centre and 22% in the North. Apart from this income perspective other socioeconomic aspects like demographic trends and urbanisation have effects on climate change adaptation.

The findings of Carraro and Sgobbi (2008) give a regional orientation where the most severe impacts of climate change are expected in Italy. They focus on four areas, which are considered especially vulnerable to climate change. These areas are (1) the Alps and glacier ecosystems, (2) coastal zones, (3) arid areas and areas threatened by desertification and (4) areas vulnerable to floods and landslides. Regarding desertification, about 5.5% of the Italian territory (16,500 km^2) are at risk of desertification (Apulia, Basilicata, Calabria, Sicily, and Sardina); economic impacts thereby occur by decrease in agricultural production or even loss of soil, soil degradation, loss of biodiversity, and additionally increased fire risk (Carraro and Sgobbi 2008). Thus, it can be stated that the areas with lower economic capacity in South Italy also face the most severe physical impacts, at least in terms of desertification.

The so called WISE study (an EC funded project on Weather Impacts on Natural, Social and Economic Systems) developed both a quantitative and a qualitative analysis of climate change impacts in Italy. The qualitative analysis (Galeotti et al. 2004b) consists of a survey,

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[37] The study deals with local estimates for Austria. We assume the climate conditions in the Italian Alps to be similar.

[38] The values are calculated for Switzerland.

conducted in two Italian regions (Lombardy in the north and Sicily in the South), shows that individuals are well aware of the outcome of extreme climate events. By looking at the survey results, there is high confidence that individuals respond to climate extremes with adaptive behaviour, although varying between the North and the South. The methodology of the quantitative analysis is based on a linear estimation procedure applied to estimate weather impacts on socio-economic sectors of interest over a time period in the past (Galeotti et al. 2004a).

6.3.1. Water (floods, sea level rise and water resources)

The hydrological cycle is a sensitive system which is affected by climate change. The main adverse effects of climate change on the water system are droughts and floods, sea level rise, the gap between availability and demand of water and low water quality.

According to the IPCC (2007) all Mediterranean countries as well as the Alp region are endangered by an increasing drought risk. The most threatened economic sectors in case of drought are agriculture and forestry on which will be focused later.

Floods could concern both the inland and the coastal zones. The melting of the Alp's glaciers could lead to river floods especially during the spring snowmelt. The coasts of the Italian peninsula will face the consequences of a sea level rise. The OECD working paper about port cities with high exposure and vulnerability of climate extremes (Nicholls et al. 2008) rank the most threatened cities. Naples is also regarded as one of these cities. The authors expect for a future scenario with the 2070's climate and population changes exposed assets of 2.49 billion USD.

In case of water resources on the one hand there are adverse effects, since both underground and surface water are vulnerable to projected climate change. Water consumption is steadily increasing whereas the amount of precipitation is either stable or decreasing. On the other hand, according to Massarutto (1999) water in Italy is relatively abundant, although regional and annual variability is high. Northern Italy can be seen as richer in water resources, while Central and Southern Italy are experiencing less water endowment. As the author further explains, agriculture is by far the largest water consumer, accounting for the usage of about 2/3 of available water resources.

Besides the quantitative impacts of climate change to water, also quality could be influenced. An increasing water temperature and as mentioned in the IPCC (2007) extreme rainfall and droughts can diminish the water quality. The most affected sectors are human health, agriculture and fishery.

Physical impacts

As presented in section 6.2.2, all climate projections for the future predict less precipitation for Italian regions with exception of the Alpine and their bordering regions. Unlike central European regions, the IPCC (2007) identifies the Mediterranean as a region with a very likely decrease in mean precipitation and a very high probability of increased droughts. Also Lehner et al. (2006) report an increased risk of drought for most of Southern Europe including Italy. Consequently, the peril of desertification is critical in some Southern and insular regions of Italy, as depicted by Figure 36:

Figure 36: Map of sensitivity to desertification. Source: Ministry for the Environment, Land and Sea 2007.

Moreover, Lehner et al. (2006) explain that projected mean precipitation doesn't predict future rainfall events adequately. Variability of precipitation could also lead to seasonal and regional variety of floods and droughts. Regarding inland water flood risk the river Po basin is considered the most vulnerable area in Italy (Carraro and Sgobbi 2008). In case of coastal floods the location of Italy should be taken into account. Italy is mostly surrounded by sea, which makes the country particularly exposed to sea level rise. The total coastline amounts to more than 7,400 km. 42% of GDP and even 59% of total population is within the 50 km zone from the coastline (Policy Research Corporation 2009). Furthermore, as Carraro and Sgobbi (2008) point out, the coastal zones are under significant anthropic pressure, which makes these areas even more vulnerable to sea level rise and extreme weather events. Although there is a certain upwards-movement of parts of Italian land, this is not enough to outweigh the expected sea level rise. Moreover some parts (The Po river basin, the Versilia, the Fondi and Pontina plains), which are already quite vulnerable to sea level rise due to their low altitude experience even a subsidence tendency. The loss of land, infrastructure and ecosystems are possible main impacts of climate change in Italy in respect of a steady sea level rise. Extreme events like storm surges have implications on human health, even on human lives and on the coastal and near-coast infrastructure.

Another problematic field due to climate change implicated seasonal water scarcity is the influence on water quality. This is linked to a high nutrient load of drinking water reservoirs through increased use of fertilisers, pesticides and irrigation in the agricultural industry. Even without considering climate change impacts, Italy is among the largest consumers of fertilisers and pesticides in the OECD (Massarutto 1999).

Economic impacts

Carraro and Sgobbi (2008) point out the importance of river floods and landslides for parts of Italy, as well as the considerable knowledge gaps concerning economic impacts. Due to the fact that impacts are mostly local and extremely uncertain, there are no estimates for nation-wide impacts to date. In a first attempt to assess the direct costs of floods and landslides at least in three Italian regions (Lombardy, Calabria and Lazio), they estimate the value of agricultural land at risk at about 103 million € for the risk of floods, and 187 million for the risk of landslides. These values refer only to the value of the agricultural property itself, not the total costs of floods or landslides and the possible indirect costs like protection or evacuation.

Carraro and Sgobbi (2008) also report about costs of climate change in the Sangro River basin of about 14 million € for 2100, by taking the increase in hydro-geological vulnerability into account it adds up to 73 million €.

Adaptation in the water sector

In Italy, the regional authorities are responsible for coastal protection; the national government is mainly active in guidance and finance support. Within the regions, the responsibility is distributed differently. That means that in some areas the regional authorities are in charge of coastal protection whereas in others it is transferred to municipalities. It is worth remarking that most of funding for coastal protection is sought at national and EU level (Policy Research Corporation 2009). This is also in line with estimates of IMF (2008), which see nearly 100% of the financial burden of coastal protection in public budgets.

Regarding the costs, according to Carraro and Sgobbi (2008) the most urgent actions to prevent floods did cost 447.36 million € and 667.88 millions for landslides up to 2006. The total costs for Italy could be as high as 42 billion €. It is remarkable that these forecasts do not take climate change into account yet, so the climate induced additional risks would increase the expected costs of preventing flood and landslide damages.

Specific economic evaluation along the Italian coast is almost limited to a small number of regional assessments. The predictions for all of Europe should help to take an overview about the overall costs of coastal protection. Afterwards particular regional adaptation measures can be focused in detail.

The final report of the Project PESETA (Projection of Economic impacts of climate change in Sectors of the European Union based on bottom-up Analysis) by the European Commission provides among other results an exceptional estimate of economic impacts and adaptation costs for coastal infrastructure through sea level rise concerning whole Europe. The results are provided in Table 23.

Table 23: Impacts of adaptation measures on residual damage of low and high sea level rise Source: EC 2009.

Scenario	**A2**				**B2**			
Sea level rise	**high**				**low**			
Adaptation	No		Yes		No		Yes	
Year	2020	2080	2020	2080	2020	2080	2020	2080
Adaptation Costs € billion/year	0.0	0.0	4.0	9.3	0.0	0.0	1.3	1.3
Residual damage € billion/year	5.9	42.5	1.4	1.8	4.4	9.3	1.0	0.9
Total costs € billion/year	5.9	42.5	5.4	11.1	4.4	9.3	2.3	2.2

The study uses two different climate change scenarios: IPCC A2 and IPCC B2. Additionally, for each scenario different sea-level rises can be assumed. For showing the extreme values, Table 23 depicts the high SLR scenario with a fast warming climate scenario (A2, high SLR) and the other side of the range (B2, low SLR). To estimate the economic impacts of climate change in 2020 and 2080 the study uses the DIVA tool[39]. The included impacts of climate change to coastal areas are: erosion, increasing risk of floods, wetland losses and saltwater intrusion. The coastal protection level which minimises the total damage equation is the "optimal" coastal protection level. The total cost of climate change follows the equation:

Total damage costs of climate change = mitigation costs + adaptation costs + residual damage

The city of Venice and its lagoon are one of the most vulnerable regions to rising water levels in Italy. The task of the project SAL.VE is to protect it from waves and storms and preserve the environment within this area.

For a specific view of the particularly vulnerable city of Venice – due to a low initial elevation and an additional land subsidence – Table 24 shows a summary.

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[39] DIVA stands for Dynamic Interactive Vulnerability Assessment, a computer tool to explore the vulnerability of coastal areas to sea level rise and to assess adaptation measures. In 2010 a new version of DIVA is expected which may result in different cost projections.

Table 24: The costs of climate change and selected adaptation strategies for the city of Venice, computed using a discount rate of 3.5%. Source: Carraro and Sgobbi 2008.

Costs of climate change in Venice in 2030	Million €
Tourism sector (decrease in tourist flows)	34.9 – 42.9
Aquaculture (clams aquaculture)	10.4 – 16.5
Damages to urban infrastructures (floors, walls and wall plasters, doors)	3.3 – 6.4
Damages caused by forced closing of economic activities (one week of high tide)	7.6 – 9.5
Social damages (city's usability)	49.2 – 86.2
Costs of adaptation measures in 2030	
Private adaptation measures (water pumps, elevation of buildings, tanks, …)	0.6
Cost of adaptation measures for harbour activities (rental mooring and mooring)	0.9 – 1.5

This outline shows only a selection of adaptation measures for the Venice area. The total costs for those considered measures range between 1.5 and 2.1 million €.

The Policy Research Corporation (2009) mentions another hard adaptation measure for the city of Venice which is not taken into account in Table 24: the MOSE-project. It is part of the SAL.VE project which was already mentioned. The objective within MOSE is to set up a sea barrier, which should temporarily separate the lagoon of Venice from the sea. Thereby the lagoon is protected from high sea tides. Most of the time the barrier lies on the sea ground and can be inflated to create a dam as a separation becomes necessary. The construction work is scheduled to be finished in 2012. Regarding the costs of adaptation to sea level rise in Italy, the importance of Venice becomes overwhelming. The MOSE-project is expected to consume more than 90% of the total Italian public expenditure against flooding and erosion. As stated by the Policy Research Corporation 2009 in the examined period 1998-2015 the MOSE-project contributes 4.2 billion € to the total costs of 4.66 billion €. These figures are not consistent with the statements at the official website of SAL.VE where the expected total costs for the MOSE project are 4.68 billion €. The Institut du Développement Durable et des Relations Internationals (IDDRI) claims that the whole Venice Safeguarding Project will draw on a budget of 15 billion USD. In their work about the Mediterranean future the time frame for these measurements is unclear, because only the starting year 1984 is given whereas the ending is unclear.

A second specific regional study is conducted by Gambarelli and Goria (2004) and deals with sea level rise in the Fondi plane, south of Rome, by using a cost benefit framework. The economic value of areas at risk is calculated and compared with costs of land protection. As the authors propose, the area studied is characterised by common features (both geomorphic and socio economic) which makes the assessment methodology appropriate for application in other Italian areas as well. In this specific case, the potential damage from sea level rise ranges between 130 and 270 million € while adaptation action (in particular upgrading the drainage system) would cost between 50 and 100 million € within a time horizon from 2002 to 2100. The study includes two adaptation options: land protection by strengthening of the present systems for land reclamation and land protection by reconstruction of a pre-existing dune as a first barrier to sea level rise. The costs concerning the former adaptation option range between 250 and 300 million €. The main part of the expenditures (200 million €) has already been assigned independently. The remaining rest of 50-100 million € is the additional amount, which is mainly due to accommodate the existing drainage system to the projected sea level rise. The latter adaptation option (the reconstruction of the pre-existing dune) would lead to costs between 12 and 15 million € for a rebuilding of a pre-existing dune and waterproofing. Furthermore in this case the value of the houses which have to be demolished is taken into account by 30-50 million €.

A study of Costa et al (2009) provides estimates derived from the "Dynamic Interactive Vulnerability Assessment" (DIVA) on economic costs and benefits of a Europe-wide flood protection against a one-in-hundred-years flood event. Here for Italy the benefits clearly outweigh the costs of such an adaptation by the year 2100 (avoided damage costs account for approximately 0.9% of the 2007 GDP, whereas the adaptation costs are only ca. 0.25%). However, in tourism prone countries like Italy one also have to take into account the political willingness to adapt by "hard" flood protection like dikes and embankments, since they can harm the attractiveness of tourism areas considerably. Eventually "soft" adaptation measures that reduce the vulnerability by flood-adapted building, insurance or early warning systems would be more appropriate in these areas, the more so as they are also so-called "no-regret"- and partly very flexible strategies (see section 0 on page 88, Hallegatte 2008).

As an example of soft protection measures, in Italy it is prohibited to build in the first 100 m from the coastline, moreover building within the 300 m coastal zone is regulated by special legislation (Policy Research Corporation 2009).

As a summary, Table 25 provides an overview of potential adaptation measures to specific climate change induces impacts in the field of water resources and sea level rise in Italy. It thereby classifies between autonomous (privately motivated) and planned (public) adaptation measures on the one hand and proactive and reactive adaptation on the other hand.

Table 25: Specific impacts and adaptation responses in the water sector.

Specific Impact	Adaptation measure	Autonomous - Private		Planned Adaptation	Nature of adaptation	
		Consumer	Producer		Proactive	Reactive
Sea level rise / Coastal floods	Spatial Planning, Prohibition of building near the coastline			X	X	
	Land protection barriers			X	X	
	Monitoring of SLR, coastal climate and the erosion of the coastal zone			X	X	
	Awareness building of the population			X	X	
	Evacuation of flood endangered areas	X	X	X		X
Higher frequency of floods	Use of insurance	X	X		X	
	Expansion of water supply and sewage networks			X	X	
	Flood-adapted building	X	X	X	X	
	Rethinking of land use in endangered areas			X	X	X
	Evacuation of flood endangered areas	X		X		X
	Urban land use planning preparation of general plans for flood risk sites			X	X	
	Coordination and Cooperation with neighbouring authorities			X	X	
	Improvement of flood protection construction		X	X	X	
	Property construction out of risk area	X	X	X	X	
	Research on regional flood impacts			X	X	
	Early warning systems			X	X	
	Flood Risk Management			X	X	
	Emergency Management			X		X
	Evaluating dam safety			X	X	
	Evaluating drainage systems			X	X	
Higher frequency of droughts / Impairment of water balance (groundwater level)	Water conservation			X	X	
	Water quality protection			X	X	
	Restriction on water use			X		X
	Responsible water use	X			X	
	Reconsidering land use management			X	X	
	Infrastructural measures (e.g. sufficient storage of water in impounding reservoirs)			X	X	
Nutrient leach into water reservoirs	Monitoring measures and reconsidering fertilisation legislations			X	X	

6.3.2. Agriculture and forestry

The agriculture sector does not play an important part in the Italian economy, since it accounts only for 2% of the total GDP and (in 2007) 3.8% of the total employment (Eurostat 2009a, ILO 2009). In 2008, the estimated agricultural output at producer prices was € 26 million (Eurostat 2009a). Nevertheless, as measured by the gross value added by agricultural production, Italy ranks second in the EU-27. The structure of the agricultural sector is diversified as it contains global market-oriented areas with typical crop cultivation as well as areas with small-scale traditional types of agriculture. Because of the limited share of agriculture in the national economy, the vulnerability of the Italian economy to climate change impacts on agriculture is expected to be low, but there may be large regional effects.

The cultivated agricultural area in Italy accounts for 13.3 million ha. It consists of 7.3 million ha of arable land, 3.4 million ha of permanent grass land and 2.6 million ha of land under permanent crops (Eurostat 2009a). 50% of the agricultural area is disadvantaged or mountainous area (Destatis 2007). The share of organic farming which puts emphasis on environmentally friendly production and animal welfare conditions is fairly high. 8.4% of the utilised agricultural area in Italy is occupied by organic crop production, 5.8% of the utilised agricultural area is fully converted (Eurostat 2009a). Almost 4 million ha are equipped for irrigation, which equals 30% of the utilised agricultural area, the second highest share in the EU-27 (Eurostat 2009a).

Agricultural production is specialised on the cultivation of olives, crop production (durum wheat, maize, soft wheat, barley and other crop species), forage crop production, citriculture and wine cultivation (Destatis 2007). In 2008, the yield of crop production (wheat, barley, maize and other crop species) was 20 million t. Wine production plays an important part in the agricultural economy. With 48.6 million hl of wine in 2008 Italy accounts for almost 30% of the wine production in the EU-27. In terms of wine exports, Italy is the leading country in 2008 (17.2 million hl) and represents 19% of world trade. 840,000 ha are used for cultivation of wine grapes (OIV 2009).

In terms of forestry the production of wood is of negligible economic importance. The amount of wood production in 2007 was 8.1 million m^3 (Eurostat 2009a). The wooded area makes up 11 million ha, which equals about 36% of the total land territory and represents 5% of total European forested area. The wood covered areas in Italy could be divided into the Northern region with temperate continental climate and semiarid in the Mediterranean region.

6.3.2.1. Climate change impacts on agriculture, livestock and forestry

It should be emphasised again that the literature on the impacts and adaptation measures and their economic costs in the case of Italy is still incomplete, although adaptation strategies in the field of agriculture have been extensively studied. Therefore, this case study relies to a minor degree on existing studies for other Mediterranean countries or on studies of the entire Mediterranean area.

Agricultural production

Temperature, incoming solar radiation, water and nutrient availability determine mean agricultural production. Thus, climate change has a significant influence on the bio-physical processes in agricultural systems and on the agricultural productivity. With respect to climate change effects, some of the factors that determine the yields are CO_2 fertilisation and nutrition, water supply, seasonal temperature, vegetation period, pests and diseases. In the following we will analyse each of these effects to picture the various effects on the agricultural production in Italy. It is remarkable that the effects of extreme weather events like hail and heavy rain with landslides, and long drought periods have not yet been researched by now. Especially the events of enduring droughts may cause severe drawbacks in the expected yields in the Mediterranean, but since these events are extremely difficult to project and their impacts differ considerably by locality and year, we focus here on the expected mean effects of long term, slow climate changes (rising temperature, decreased precipitation and higher CO_2 concentration). However, one always has to keep in mind the rising variance in yields due to an expectedly higher probability and intensity of extremes.

- *Temperature range and vegetation period*

Temperature as well as day length control the duration of the growth period, until the plant reaches maturity. Increased temperatures will lead to an accelerated development and a reduction of the growth period of determinate[40] crops with a shorter duration of the grain-filling period. For determinate crops the reduced duration to maturity will result in a reduced yield. But higher temperatures will increase the yield for indeterminate crops.

Cereals, seed and protein crops are determinate crops. Indeterminate species include tubers and root crops such as potatoes, carrots, and sugar beets.

In Southern Italy, cereals are among the most important crops. In the past twenty years, South Italy accounted for 68% of national durum wheat production. The Sicily and Puglia regions produced the largest part of durum wheat. The regions Abruzzo and Campania produced large quantities of soft wheat. Barley, oats and corn are less common (Di Falco and Chavas 2008). Increasing temperatures and drier conditions in the Mediterranean region will lead to a slight yield reduction, of which wheat will be especially affected (Maracchi et al. 2005). The effect can be counteracted by cultivation methods, different choice of species and crop biodiversity, as pictured in the following section on adaptation measures in agriculture.

For seed crops, e.g. sunflower in Southern Italy, a temperature increase will shorten the length of the growing period and possibly reduce the yield (Peiris et al. 1996).

Because of higher temperatures, the cultivation of perennial crops such as olives, grapevine or fruit trees is becoming more important. For instance, grapevine as a perennial plant requires relatively high temperatures.

Horticultural crops include vegetables and ornamental crops that are either field-grown or grown under protected conditions. Field-grown vegetable crops, e.g. carrots, will generally benefit from increasing temperatures. But for determinate crops, such as onions, higher temperatures will reduce the duration of crop growth and therefore lead to a reduction in yield (Maracchi et al. 2005).

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[40] Determinate crops are sensitive to water stress during certain periods of growth (especially during seed formation). Moisture stress during seed formation can lead to an irreversible interruption of the process. Indeterminate crops are insensitive to moisture stress throughout the growing period. Water shortage will rather affect quality than yields.

- *CO_2 fertilisation effect*

The growth of plants and therefore the agricultural productivity is generally expected to be influenced positively by the increase of CO_2 concentration in the atmosphere. However, the actual impact of the CO_2 fertilisation effect depends strongly on the temperature and on the overall supply with nutrients and water. The CO_2 effect is of minor relevance if the plant is exposed to high temperatures, water shortages and deficiency in nitrate supply.

The increase of CO_2 in the atmosphere could predominate other climate change effects and therefore a large increase in wheat yield potentials could occur in Italy (Harrison and Butterfield 2000). However, a critical remark on such prospects is that the realisation depends on an optimal input of all other conditions like water and nutrient supply as well.

Since maize is a C_4-plant, the fertilisation effect by higher CO_2 concentration is of less importance. A decrease in yield is expected, because the negative effects of higher temperatures on the duration of the growing season outweigh the CO_2 effect. As a measure to prevent from decreasing productivity the use of other maize varieties is proposed (Wolf and van Diepen 1995).

The yield of seed crops such as soybean will increase due to a positive effect of CO_2 concentration on growth and only a small effect of temperature on the duration of crop growth (Wolf 2000).

Root and tuber crops are influenced positively due to rising CO_2 concentration. Sugar beet may benefit from higher temperatures and an increase in CO_2 as well, since it is not determinate in its development (Davies et al. 1997).

Vegetables are also expected to respond positively to the CO_2 effect. For lettuce, temperature has only little effect on yield. Thus, the net effect of CO_2 fertilisation and temperature rise is positive (Maracchi et al. 2005).

Perennial crops such as grapevine, olive and energy crops do strongly respond positively to the CO_2-effect. Yields in grapevine may be strongly stimulated by increased CO_2 concentration without negative repercussions on the quality of grapes and wine. However, within viticulture an increase in yield variability (fruit production and quality) is expected (Bindi et al. 1996). The suitable area for olive cultivation could be enlarged in Italy as has been shown in a reference scenario by Bindi et al. 1992. Indeterminate energy crops are favoured by a longer growing season and by increased water use efficiency due to higher CO_2 levels.

- *Water supply*

Climate change will change the amount of seasonal precipitation and its pattern of variability, as presented in section 6.2. A change in rainfall and soil water availability may affect the duration of growth and the photosynthetic efficiency. Lower rainfall increases the level of environmental stress which can be the cause of lower yields and possible crop failure. The effects of water stress vary between plant species. Determinate crops including cereal crops and oil seed crops are most sensitive to water stress during reproductive stages. Indeterminate crops including tubers and root crops are relatively insensitive to water stress and have no specific critical periods during plant growth. Forage crops are grown for hay, pasture, and biomass production. Perennial forages are least sensitive to water stress. Measures to anticipate water stress like crop selection, irrigation systems and management techniques are important and will be further developed in the section on adaptation in agriculture.

The demand for water for irrigation is projected to rise in the Mediterranean regions. Agriculture is the sector with the highest share in water consumption (50%), mainly due to irrigation. In 2003 the irrigable area of Italy was almost 4 million ha; the area actually irrigated 1.8 million ha. 55% of agricultural production is obtained by irrigated systems. 60% of Italy's agricultural exports are irrigated crops. Irrigation is important for crop production due to high evapotranspiration and restricted rainfalls. Therefore, drier conditions as an effect of climate change will lead to higher water consumption per area unit. In addition, peak irrigation demands are expected to rise because of heat waves (Olesen and Bindi 2002).

- *Vermin and plant diseases*

The proliferation of insect pests is dependent on the temperature. A warmer climate enhances the proliferation of insect pests and warmer winter temperatures allow pests to overwinter, which may lead to greater and earlier infestations during the following crop season. Stress situations in extreme weather periods may lead to a higher occurrence of pests. Water and temperature stress will also promote the spread of plant diseases. The influence of changing climatic conditions on the interaction of crops and diseases, however, has not yet been studied thoroughly (Olesen and Bindi 2002). Weeds are directly influenced by a changing climate. Higher CO_2 concentration will stimulate growth and water use efficiency of weeds. The control of weeds, pests and diseases by pest management systems is expected to be affected by changing environmental conditions.

Table 26 summarises the impacts of climate change effects on the bio-physical processes on agricultural crops and on agricultural productivity (without vermin and diseases). The overview of several studies shows the relative change in yield. It should be emphasised that these studies consider different scenarios and also make different assumptions on adaptation processes, so the given net effects can serve only as a rough orientation. In addition, extreme weather events like droughts or irreversible effects like desertification or sea level rise and their repercussions on the agricultural production are mostly not considered. Nevertheless, all studies take into account the influence of changing climate conditions and increasing CO_2 concentration on agricultural systems.

Table 26: Influence of changing climate conditions on expected yield of agricultural crops in Italy.

Crop	Higher temperatures	Water shortage	CO_2 effect	Yield increase/ decrease	Source
Cereals (e. g. durum, soft wheat)	-	-	+	(-)	Maracchi et al 2005, Butterfield 2000
Seed crops (e. g. sunflower)		-		-	Wolf 2000
Perennial crops (e. g. olives, grapevine, fruit trees)	+		+	+	Bindi et al. 1992, 1996
Protein crops (e. g. soybean)	-		+	(+)	Wolf 2000
Indeterminate vegetables (e. g. carrots)	+			+	Maracchi et al. 2005
Determinate vegetables (e. g. onion)	-			-	Maracchi et al. 2005
Root and tuber crops (e. g. sugar beet)	+		+	+	Davies et al. 1997

The three columns in the middle summarise the specific impacts of climate change effects on bio-physical processes. A '+' indicates a positive effect, a '-' indicates a negative effect on the crop. The fifth column gives a summary of the expected relative change of yield. If the relative change of yield is expected to be of minor extent or unsure, this is indicated by brackets.

Livestock production

The Livestock system could be influenced by climate change in two different ways: on the one hand direct effects on animal health, growth, and reproduction and on the other hand indirect effects on availability and price of animal feed (Olesen and Bindi 2002).

If the effect of increased CO_2 fertilisation outweighs the effect of higher temperatures, the yield of forage crops will increase at the expense of a decrease in digestibility. If temperature effect dominates, the vice versa results are expected. However, the resilience to climate change may be enhanced by a higher diversity of forage crop species and by improved management techniques. The requirements for insulation and air-conditioning might be affected by global warming, higher radiation and wind, which might increase or decrease housing expenses depending on the climatic conditions of the geographic region (Cooper et al. 1998).

Forestry

Forest ecosystems respond to impacts of climate change by boundary shifts (e.g. expansion of thermopile tree species) and changes in productivity. By and large, forest productivity is generally expected to increase due to global warming, increasing CO_2 fertilisation and increased nitrogen deposition. However, the impacts are regionally more ambivalent: In Northern Italy, the mentioned beneficial factors are assumed to enhance forest productivity. In contrast, an opposite trend can be expected in the Southern part of the country: The increased aridity observed makes the Italian forests more vulnerable to biotic and abiotic disturbances reducing their resistance and resilience. Besides, dry weather and damaged ecosystems with accumulation of dead biomass increase the risk of forest fires. Nowadays, an average of 55,000 ha of woodlands is already more or less seriously damaged by fires every year. The cause of this phenomenon is by a third related to arson, wrong behaviour and inattention (Ministry for the Environment, Land and Sea 2007). The consequences for the natural balance are grave and the time for recovering is long. Indeed, one might say that the risk has decreased as a result of strong sensitisation campaigns and due to an improved organisation of the regional and national fire prevention system[41]; but nevertheless reduced precipitation in combination with higher temperatures favours an increase of the risk of fire damages and will also promote pest and pathogen development (Maracchi et al. 2005). In addition, it is worth mentioning that about 3% of forests are located along areas at risk of subsidence.

It follows that about one third of the Italian forests is seriously jeopardised by climate change. This will inevitably imply a significant loss in habitats and biodiversity (Ministry for the Environment, Land and Sea 2007).

6.3.2.2. Vulnerability of agriculture and forestry

The vulnerability of the agricultural sector in a certain geographical area depends on the different climate conditions and constraints which are predicted for the different regions. As aforementioned, Italy can be divided along two climatic zones, the Alpine region in Northern Italy and the Mediterranean region in Southern Italy. For the Mediterranean area, the projected climate change will have little beneficial effect on agriculture and disadvantages are preponderant. The combined increase in temperature and reduction in precipitation will enhance the problem of water shortage. Additionally, there is an increase in climatic inter-annual variability and a higher probability of extreme temperature events (Böhm 2008, see Figure 33). The increase in summer water shortage, the shorter growing period to reach maturity and heat stress will lead to lower harvestable yields, higher yield variability and a reduction in suitable areas for traditional crops (Olesen and Bindi 2002, Maracchi et al. 2005). Extreme weather events like heat spells, droughts or heavy storms can lead to incidental crop losses which come along with high economic losses.

Cereal yields, which are predominant in Southern Italy, are limited by water availability, heat stress and short duration of the grain filling period. For certain varieties of crops which are grown near their limits of maximum temperature tolerance, spells of high temperatures can be extremely detrimental (Olesen and Bindi 2002). A reduction of suitable areas for traditional crops is expected. “This may be overcome by the introduction of new crops” (Maracchi et al. 2005).

Permanent crops as olives, grapevine or fruit trees are particularly vulnerable to extreme weather events, which can lead to a yield reduction or a complete destruction. The yield variability of grapevine regarding fruit production and quality is expected to be higher in the current production areas, which are economically important. “Such an increase in yield variability would neither guarantee the quality of wine in good years nor meet the demand for wine in poor years, thus implying a higher economic risk for growers” (cited from Bindi et al. 1996).

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[41] The surface burnt decreased from 190.640 in 1985 to 76.427 in 2001 (Ministry for the Environment, Land and Sea 2007).

The frequency of droughts is the main factor for Mediterranean forests constraining growth and productivity. "The vulnerability of forests will be very high in the Mediterranean region. This is mainly due to the summer precipitation, which no longer supports the present forest cover. This negative effect will be further enhanced by increasing the fire risk." (cited from Maracchi et al. 2005)

As mentioned in section 6.3, desertification is an expected problem in parts of Italy. Several regions in Southern Italy are particularly at risk of desertification (Apulia, Basilicata, Calabria, Sicily, and Sardina). Therefore, soil degradation, increased salinity or even loss of soil will lead to a decrease in agricultural production with high economic impacts at regional level. There are several studies for developed countries which quantify the risk of desertification in relation to its impact on agriculture in terms of costs. They estimate the agricultural losses between 40% and 70% (Carraro and Sgobbi 2008).

Coastal areas of Italy as the river Po basin (Emilia-Romagna), the Fondi and Pontina plains or the Sangro river basin (Abruzzi) are affected by the sea level rise, which might lead to a salinisation of water resources. Increased risk of floods and landslides as a consequence of climate change may affect crops and agricultural land. In the forestry sector, higher frequency of droughts will lead to a higher risk of forest fires (Carraro and Sgobbi 2008). Probably this will correspond with high economic losses.

Drier soil conditions will increase the vulnerability to wind erosion. Soil erosion may also be the effect of a larger frequency of high intensity precipitation events due to higher gradients of temperature and pressure (Favis-Mortlock and Guerra 1999).

6.3.2.3. Impact assessment and adaptation strategies

Impact assessment

The physical and biological impacts on the agricultural production were presented in the previous sections. However, the impact of climate change is only one determinant of yields and revenues in the Italian agricultural sector. Other important triggers are socio-economic factors, the market situation and international competition, technological development and policy choices. Therefore we will raise some of these issues other than climate change in the following. We will not explain them completely, but nevertheless an analysis of the agricultural sector cannot be complete without notices on these issues.

Even though the Italian agricultural sector contains market-oriented technologically specialised farming systems, its productive capacity can be further enhanced by technological development. Especially for cereal crop production the yield will not only depend on climate change effects but also on technological progress. Olesen and Bindi (2002) calculate the yield gap, which is defined as the difference between estimated yields under optimal management and the actual yields in 1995-1999. The yield gap therefore can be interpreted as a measure for the potential of a yield increase which is driven only by an optimised use of technology. For the Mediterranean area, the yield gap accounts for two third of the yields in 1995-1999, which is the highest value in comparison to other western European countries. Thus, for Italy technological progress offers a high potential for agricultural productivity and the possibility to compensate for negative effects of climate change. Also for smaller traditional farming systems farm management improvements and adaptation of farming practices can anticipate the negative impacts of climate change.

Concerning another important determinant of agricultural revenues, EU-policies, Olesen and Bindi (2002) formulate the goal of national or supranational policy as the development of "a sustainable agriculture that also preserves environmental and social values in the rural society". In the context of climate change, policy has to help farmers to adapt agricultural production to changing climatic and environmental conditions. Policy should, for example, support the flexibility of land use, crop production and farming systems. The considerable level of state intervention in the EU agriculture is due to the fact that the sector plays an important role in landscape management, in rural development and food security. However, policy measures are also needed to develop strategies to mitigate climate change through a reduction of detrimental emissions.

Regarding the national adaptation activities mentioned in section 6.1, there is the CLIMAGRI project which explicitly focuses agriculture. On a supranational level, the legal framework of the EU including the Common Agricultural Policy (CAP) is of particular importance. The EU White Paper lays out a European framework for action to improve resilience to climate change. It contains a description of implications for the CAP to facilitate "adaptation to the changing conditions by helping farmers to adapt their production to the changing climatic situation and to provide wider ecosystem services dependent on land management" (EU 2009). These projects and accentuations in EU policy papers illustrate the importance of agriculture for policies and policy advice projects and show that climate change impacts on agricultural revenues cannot be considered without including policy choices. Since the assessment and prediction of policy choices and world market development cannot be performed in the scope of this documentation, the analysis of agricultural revenue development must be interpreted as partial.

6.3.2.4. Adaptation strategies

Adaptation measures range from autonomous short-term adaptation at farm level which includes improvement of agronomic techniques and farm management to long-term adaptation at sectoral level as a result of policy measures. Apart from this differentiation,

Table 27 on page 133 gives an overview of planned and autonomous adaptation measures.

Short-term adjustments

Short-term adaptation to climate change can be to some extent regarded as a normal adjustment of the production processes to changing weather conditions or to market forces because they follow the same principles. They are autonomous in the sense that they are implemented at farm-level and involve no major system changes.

The production of crops and thereby the profitability can be optimised by adaptation to the longer growing season, higher temperatures, and the increase in CO_2 concentration. By using indeterminate long season cultivars the yield security in changing climatic conditions can be increased. Higher temperatures allow the cultivation of thermophile plants like maize and soya (e.g. for biomass production). Earlier planting or sowing dates and the use of suitable crop varieties can help to avoid heat and water stress and reduce irrigation requirements (Maracchi et al. 2005, Olesen and Bindi 2002). The use of fertiliser can support increased crop growth and nitrogen uptake by the crop, which is triggered by the projected increase of atmospheric CO_2. Nutrient management including fertiliser placement and timing can help to reduce the quantitative use of (synthetic) fertiliser. Water conserving practices to combat drought (e.g. conservation tillage[42] and irrigation scheduling) can be adopted to anticipate water shortage. Conservation tillage retains moisture and increases the infiltration of rainfall into the soil. It also helps to protect soil from erosion. Irrigation management allows for concentrating the watering effect by proper timing of the amount of distributed water. Since global warming will lead to a higher incidence of pests, diseases and weeds, the adoption of integrated pest management systems helps to address these problems and to avoid larger use of pesticides. The growing of mixed and suitable species also offers a resistance against diseases and vermin (Di Falco and Chavas 2008).

Long-term adaptation

While the aforementioned adaptation measures may be sufficient in short-term, in the longer run structural changes to adapt to climate change and the development and implementation of optimal agricultural technology and production will become necessary, thus requiring a fundamental strategy for adaptation and the building of a knowledge base of climate change impacts and adaptation measures.

Such knowledge bases may include optimal management techniques (e. g. minimum tillage, stubble mulching, etc., see Olesen and Bindi 2002) and management strategies (e.g. irrigation scheduling) to improve the efficiency of irrigation and nutrition. Long-term sectoral-level adaptation may also include changes of land use and land allocation especially in vulnerable areas such as Southern Italy. For example, crops with high inter-annual variability in production (e.g. wheat) may be substituted by crops with lower productivity but stable yields to stabilise agricultural production. The selection of suitable crops and the development of new crop varieties, which are resistant to heat and water stress or changing diseases and pests, can be supported by research of genetic resources or crop breeding through traditional and biotechnical techniques (Olesen and Bindi 2002).

Example of crop biodiversity as a long term adaptation measure

Agricultural biodiversity has a crucial role in the long term adaptation process to a changing climate. It supports resilience and maintains the agricultural productivity. There are two reasons for the beneficial role of crop biodiversity. Firstly, the use of more diverse crop species increases the probability of growing crop species which are best-adapted to the environment. Secondly, since different crop species have different characteristics a high variety offers the best “potential to resist biotic and abiotic stresses both in the short and the long term” (Di Falco and Chavas 2008).

Di Falco and Chavas (2008) investigate the role of crop biodiversity in reducing the possible negative impacts of climate change. Their analysis is based on data for cereal production of eight regions in Southern Italy for the period between 1970 and 1993. The dry climate of the Mediterranean area favours the production of cereals. The area is expected to be affected by climate change impacts: A decline in rainfall between 5% and 15% is forecasted by IPCC climate change projections. Therefore the authors consider also the impact of different permanent changes in rainfall. The econometric analysis gives the following results:

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[42] Conservation tillage is a land management technique, which leaves some or all crop residues of the previous season on the soil.

- Crop biodiversity has a positive and fairly large impact on productivity both in the short and long run.
- The long-run impact is much larger than its short-run impact.
- The role of biodiversity varies with rainfall.
- The productivity benefits of biodiversity are larger when rainfall declines and the ecosystem faces environmental stress.

Furthermore, the authors looked at several climate change forecast scenarios. In addition to the base scenario, they investigate the effect of alternative levels of crop biodiversity (5%, 10%, and 15% permanent decline). With a dynamic simulation based on their model, they can show that a reduction in crop biodiversity has a negative effect on the productivity of the agricultural system and that the losses are much higher in the long run than in the short run. For example, under a 15% reduction in diversity, production decreases by 14% in the short run (i.e. within one year), but as much as 45% in the long run (i.e. for more than 6 years).

The authors use their model to analyse the interactive effects between declines in rainfall (10%) and an increase in biodiversity (2% and 3%), to further investigate the resilience benefits of crop biodiversity, They found that under a rainfall decline of 10% and an increase in biodiversity by 2%, the production will be reduced by 6% in the short run and by 3% in the long run. In a scenario with an increase of biodiversity by 3%, the reduction of productivity would account for only 3% in the short run, while in the long run it could even be compensated. The authors come to the conclusion that even though crop biodiversity cannot prevent the lower rainfall from decreasing agricultural productivity, it can support resilience of the agricultural system and therefore plays an important role in adaptation to climate change: "[…] under climate changes, enhancing the biodiversity of an agro ecosystem can help maintain its long term productivity and its ability to produce food" (Di Falco and Chavas 2008).

Table 27: Specific impacts and adaptation responses in the agricultural sector; *) e.g. in the case of state intervention improving the competitiveness of bio-fuel.

Specific Impact	Adaptation measure	Autonomous - Private		Planned Adaptation	Nature of adaptation	
		Consumer	Producer		Proactive	Reactive
Longer vegetation season and increased temperature	Planting of long-season cultivars		X			X
	Earlier planting/sowing or earlier crop variety		X			X
	Planting of indeterminate varieties		X		X	X
	Developing of new crop types		X		X	
Increased CO_2 fertilisation	Increased use of fertiliser and nutrients		X		X	X
	Nutrient management		X		X	
Global warming and water shortage	Irrigation scheduling		X		X	X
	Land management techniques (e.g. conservation tillage)		X	X	X	
Increased incidents of pests and weeds	Increased use of pesticides		X			X
	Pest management system		X	X	X	
Increase in extreme weather events	Use of insurance		X	X	X	
	Floods: evaluating water protection guidelines			X	X	
General impacts	Crop biodiversity		X	X	X	
	Crop breeding		X	X	X	
	Building of germ-plasm banks		X	X	X	
	Change in land use (e.g. biomass or forage production)		X	X*)	X	X
	Rearing more resistant crop types		X	X	X	
	Increased use of fertilisation and plant protection (neg. externalities)		X		X	X
	Water-saving cultivation		X	X	X	X
	Research on regional climate change			X	X	

6.3.3. Tourism (Alpine areas, coastal areas)

Tourism in Italy comprises the coastal as well as the alpine areas. The coast side is mainly visited during summer, whereas the alpines are primarily visited for winter tourism. Mediterranean area is one of the most popular tourist destinations. Its climate is generally considered as quite, benign and delightful. The annual migration of Northern Europeans to the countries of the Mediterranean coast in search of the traditional summer ‘sun, sand and sea’ holiday in combination with historical and cultural sites is the largest single flow of tourists across the globe, accounting for one-sixth of all tourist trips in 2000. This large group of visitors, totalling around 100 million per annum, spends an estimated € 100 billion per year (Ministry for the Environment, Land and Sea 2007).

In 2006, Italy was the second biggest tourist destination measured as per-night stays by non-residents in Europe (Eurostat 2008). Any climate-induced change in these tourist flows and induced income would have very large implications for the Italian tourist destinations involved. This shows the high vulnerability of the Italian economy in respect to climate and macroclimate changes and the thereby induced possible shifts of tourist flows.

Physical impacts

The retreat of glaciers could cause severe aftermaths, such as a higher likelihood of rockfall through additional exposure of sediment and less permafrost (Alcamo et al. 2007). A higher temperature combined with a possible increase in precipitation is likely to lead to an intensity of rainfall events in winter and increased snow melt down, enhancing the flooding risk in alpine and adjacent areas.

Furthermore, extremely hot temperatures in the summer are likely to occur in the future, which could be largely unfavourable to summer tourism especially in coastal areas (Alcamo et al. 2007). Besides higher mean temperatures which to some extent human organisms can adapt to, particularly extreme heat waves like in the summer of 2003 stress the well-being of humans and consequently may have adverse effects on the attractiveness of Italy as a tourist site (Carraro and Sgobbi 2008).

Economic impacts

One region which his expected to be particularly affected by climate change is the Alpine region. According to Bigano and Bosello (2007), tourists visiting the Italian mountains in 2006 were spending 6.6 billion €, which is 18.5% of the total tourism expenditures in Italy. More than 90% of this expenditure takes place in the Alpine region.

Italy belongs to the major skiing destinations in Europe. Therefore the winter tourism industry contributes strongly to the economy of the country (OECD 2007). For different climate change scenarios and snow cover, the Italian Alpine region as a whole is expected to experience an average income loss of 10.2% in the medium term in 2030 compared to the baseline income of 2006.

Galeotti et al. (2004a) attempt to estimate the impact of extremely hot summers on tourism inflow to Italy, using data for the period 1986–1995. On average, extremely high temperatures in July lead to a decline in bed-nights of almost 40,000. A 1°C-temperature rise in the winter period causes an average loss of tourist inflow of 30,000 bed-nights. Nevertheless, a careful interpretation needs to be done. As the analysis is looking backwards, a quantitative projection for the future could only hold when other influential factors do not change.

Adaptation in the tourism sector

The OECD (2007) divides the adaptation measures into technological and behavioural ones. Whereas the adaptation of coastal destinations is strongly connected to coastal protection and a possible shift of holiday seasons, the Alpine tourism industry requires different methods to adapt. The main available technological solutions are: artificial snow-making, developing north facing slopes; extending and improving existing ski areas to higher elevations; slope development; and planting of trees to protect the slopes.

The main ski areas of Italy are situated where the altitude of the natural snow-reliability line is at 1,500 m (OECD 2007). An increase in temperature will raise this line higher. The authors of OECD (2007) made predictions for the year 2050. The 1°C scenario would shift the line to 1,650 m, at 2°C the snow-reliability line is expected at the height of 1,800 m. The largest shift to 2,100 m will occur at a temperature increase of 4°C. Comparing to other German skiing areas within the Alps Italian territory is not as much sensitive as for example Germany, because it lies in higher altitudes. On the other side the higher the skiing area already exists, the limited the possibilities to evade rising degrees by shifting to upper parts. Furthermore the higher the skiing area the more they are windswept. Moreover the OECD (2007) points out that the extension to higher parts is expensive. At the moment there are no studies about the costs for the expansion of skiing areas to higher altitudes within the Italian region.

Nowadays artificial snow is the most used adaptation strategy. About 77% of the Italian ski areas are already covered by snowmaking systems (Ministry for the Environment, Land and Sea 2007). CIPRA (2004) estimated that in the Italian Alps out of a terrain of 22,600 ha about 9,000 ha are covered by snow-making. Both in absolute numbers as well as in shares the Italian skiing area covered with artificial snow is the second largest one, after Austria. In South Tyrol there even can be 70-80% of the area artificial snow.[43] The future trends of snow-making aren't predicted in detail so far. CIPRA (2004) expects an extension especially in areas where at present few snow-making devices exists. The costs for snow-making depend on investment and running costs. The information about investment is rare, but CIPRA (2004) mentions that for Switzerland one kilometre of ski run will require investments of 650,000 €. The Austrian 254 operators spent in 2009 as a whole 163 million € for installing and modernisation of snow-making machines.[44] The running costs depend on the amount which is needed, water and electricity as well as staff costs. There are some figures of special areas in Switzerland about these costs, but none about Italy, but CIPRA (2004) admit that the cost differ not also between countries but also between regions. For that reason the expected specific running costs for Switzerland can't be used for Italy. Nevertheless CIPRA (2004) assesses the current average expenses for one m³ at three to four € (including depreciation, energy and personnel costs). For calculating the costs for Italy we also need to know the average necessary deepness of snow. The province South Tyrol assumes a deepness of 30 cm[45]. In case of Italy the current area which is suitable for artificial snow has size of 9000 ha. Taking the necessary 30 cm deepness of snow into account, 27 million m³ artificial snow is needed. The average costs will amount 81-108 million € based on the average expenses of 3-4 €/m³. These expenses are only an approximation for artificial snow within the suitable current Italian area for covering the whole area once. The real expenses are not easily to calculate, because they depend on the frequency of snow-making. How often the snow runs have to be covered by snow-making is influenced by four main variables: location (height and whether the slopes are north- or south-faced), temperature, weather and number of skiers. All this insecurities make it difficult to give a concrete figure about the current and future expenditures of snow-making in Italy. The division in public and private adaptation of these expenses is not regulated nationwide in Italy. The costs are mainly beard by the cable railway operators and therefore private autonomous adaptation. CIPRA (2004) mentions that the operators demand support by public authorities, especially by municipals and by regional service providers within the winter tourism sector. In case of Italy in the report only South

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[43] http://www.provinz.bz.it/wasser-energie/wasser/beschneiung.asp

[44] http://www.seilbahnen.at/presse/aktuell/2009-10-01factsheet

[45] http://www.provinz.bz.it/wasser-energie/wasser/beschneiung.asp

Tyrol is mentioned. There investment cost are publicly subsidised by 23%. However, this strategy is extremely energy and water intensive and therefore ecologically and economically highly controversial. The province of South Tyrol claims that 1 m³ of water is needed to get 2.5 m³ of snow. The energy consumption for snow-making depends not only on quantities but also on temperatures (OECD 2007). Increasing temperature is accompanied with a higher energy consumption to freeze the water. According to Carraro and Sgobbi (2008), a possible role for public intervention is in defining priorities regarding the water and energy consumption. In Italy only South Tyrol has regulations for snow-making.

So there is a need for other adaptation strategies other than technical ones. New business models that can lead to winter revenue diversification, including both snow related and non snow-related offers (health tourism, congress tourism, other sports and popular activities, etc. - Ministry for the Environment, Land and Sea 2007). The withdrawal from ski tourism takes is observed only in a few regions. CIPRA (2004) only mentions German examples. This may rely on the higher vulnerability of German skiing areas, because of their low altitudes. The OECD (2007) projects that these behavioural adaptation strategies will be put more into practice under a further worsening climate change.

Summarising, adaptation measures in the field of tourism seem to be very fragmentary and a lot of action still needs to be done, e.g. developing alternative income sources instead of tourism, promotion of alternative tourist programmes like hiking instead of winter sports. The existing adaptation measures are essentially partly reactive and in the long run cost-intensive and can therefore not be considered as sustainable long term solutions.

Table 28 gives an overview of realised and other possible adaptation measures. Again it differentiates between planned/autonomous and proactive/reactive adaptation measures.

Table 28: Specific impacts and adaptation responses in the tourism sector.

Specific Impact	**Adaptation measure**	**Autonomous - Private**		**Planned Adaptation**	**Nature of adaptation**	
		Consumer	**Producer**		**Proactive**	**Reactive**
Shortened snow cover period	Using artificial snow (ecologically and economically controversial)		X			X
	Visit higher altitude winter resorts	X				X
	Move infrastructure to higher altitudes		X			X
	Reconsideration of water and energy use guidelines			X	X	X
	Diversification of alpine tourism industry		X		X	X
Hot summers	Increased use of air conditioning (controversial)	X	X			X
	Innovative house designs		X		X	
	Normative framework for construction design			X	X	
Sea level rise at touristic sites	See section 6.3.1		X	X	X	X
Increased occurrence of algal blooms	Control of bathing quality			X	X	
General impacts	Changing in recreation and travel behaviour	X				X
	Expansion of current research			X	X	

6.3.4. Health

6.3.4.1. Basic outline

The National Health Service (NHS) in Italy was founded in 1978 to expand public health care services. The system was reformed during the period 1997 to 2000, where also the decentralisation of administrative and fiscal responsibilities to the regions was launched. According to the WHO (2007), about 15% of the population has complementary private health insurance, either individually subscribed or offered by employers. OECD (2009) reports that Italy spent 8.7% of GDP for health in 2007 (adjusted for purchasing power parity). This is slightly more than Finland's expenditure with 8.2% of GDP but clearly lower than Germany's spending of 10.4% of GDP. The public sector is the main source of health funding in nearly every OECD country. This is also valid for Italy, where 76.5% was funded by public sources in 2007 (OECD, 2009). Figure 37 gives an overview of the total health expenditures as a share of GDP in 2007 within the OECD countries. Figure 38 shows the public share of health expenditure in detail.

Figure 37: Total health expenditures as a share of GDP 2007. Source: OECD (2009).

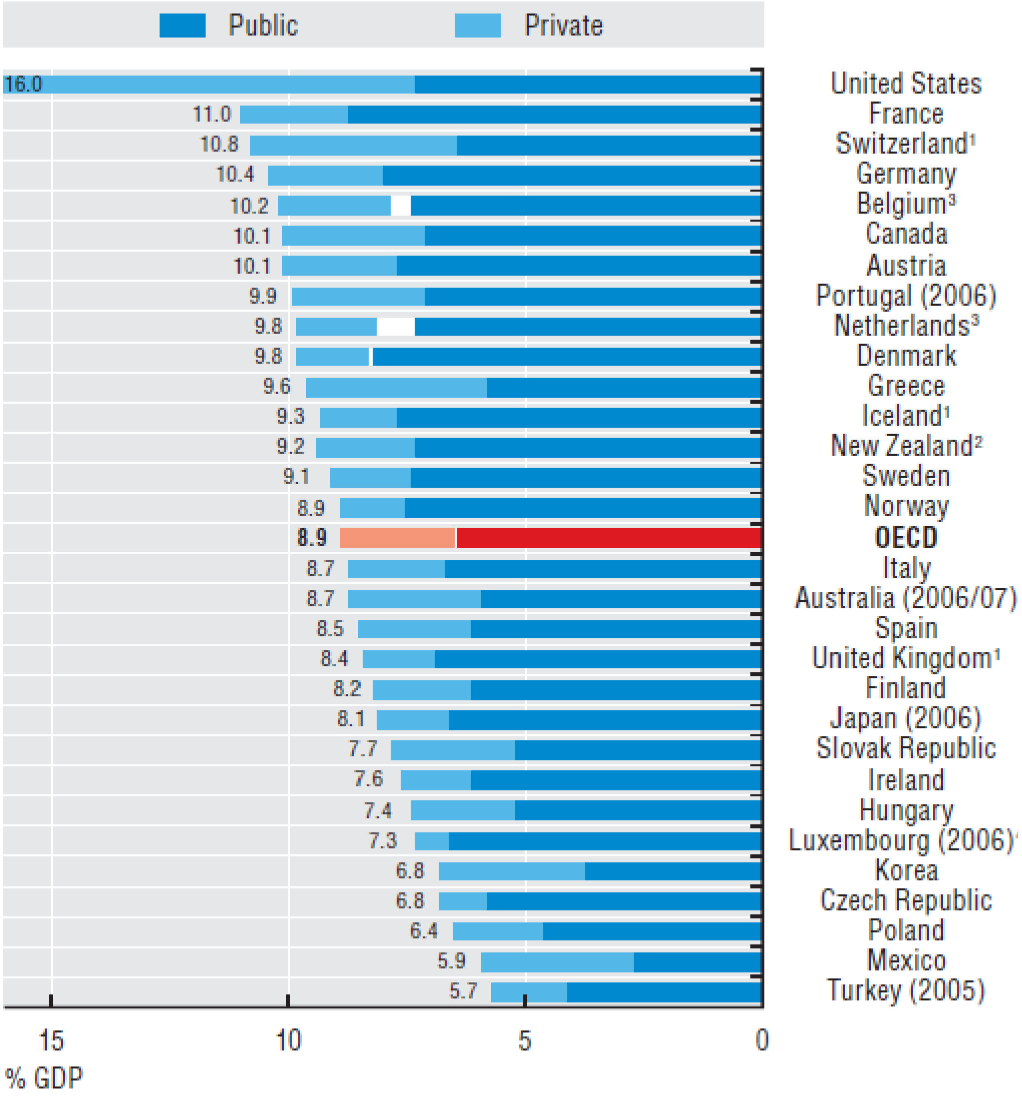
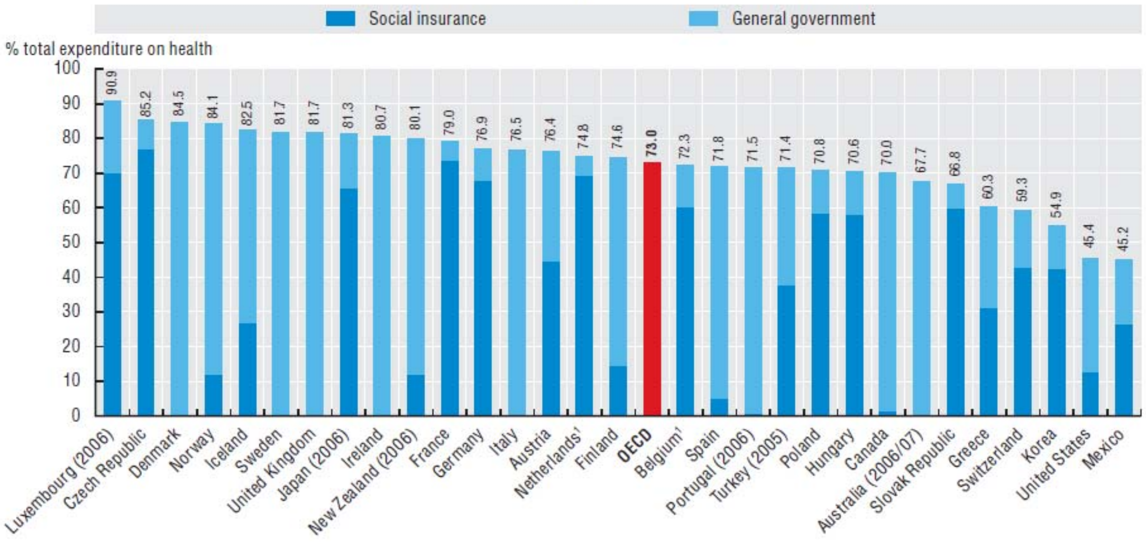


Figure 38: Share of public health expenditure in detail. Source: OECD (2009).



6.3.4.2. Climate change impacts on human health

The case studies about Germany and Finland dealt with human health in the climate change context as well. There the distinction to direct and indirect effects of climate change on human health has been already mentioned.

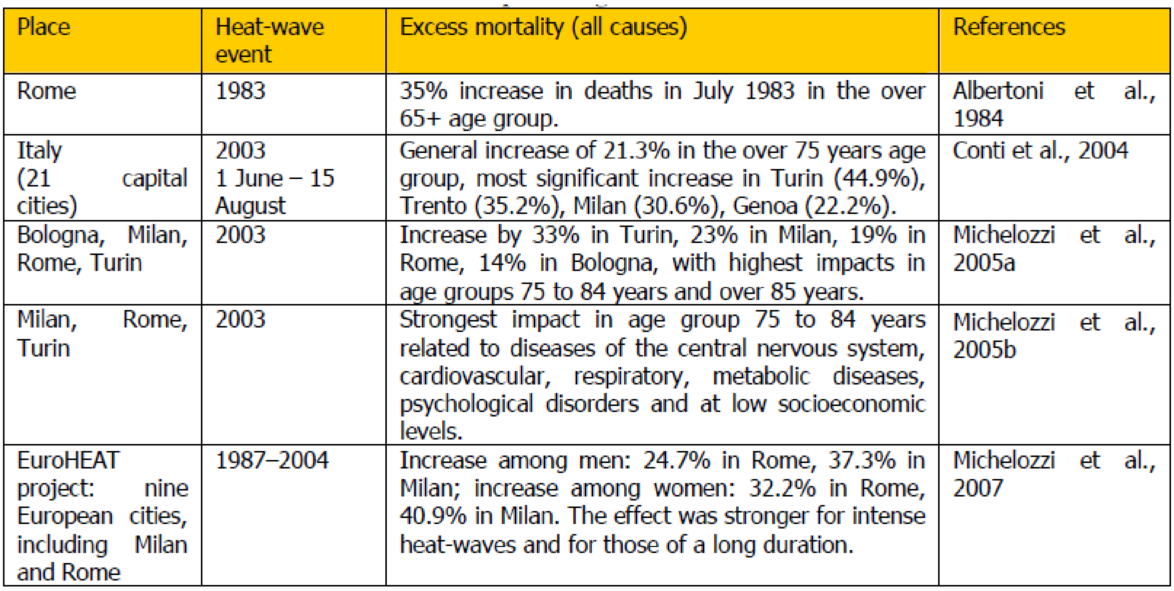
6.3.4.3. Vulnerability and adaptation

In case of Italy especially, heat waves and floods are the main threats to human health. The responses to expected impacts of climate change on health are observed by the European project cCASHh (Climate Change and Adaptation Strategies for Human Health). The main objects of public health services should therefore be in the following areas: early warning, assessment, policy development and service assurance.

Heat waves

The IPCC report mentions the connection of mortality and heat and cold. Italy within the Mediterranean area is likely to getting hotter and more heat waves are expected. The last extreme heat wave over Europe in 2003 raised the temperatures by 3 to 5°C (IPCC 2007). Furthermore the most severe impacts from climate change to human health are expected to be heat related (IPCC 2007). The WHO came to the conclusion that on average an increase of 20-30% of daily mortality in the population over 75 years is expected during next heat waves. The WHO collected the current literature about heat waves and the resulting excess mortality. The overview is shown in Table 29.

Table 29: Environment and health risks from climate change and variability in Italy. Source: WHO (2007).



Place	Heat-wave event	Excess mortality (all causes)	References
Rome	1983	35% increase in deaths in July 1983 in the over 65+ age group.	Albertoni et al., 1984
Italy (21 capital cities)	2003 1 June – 15 August	General increase of 21.3% in the over 75 years age group, most significant increase in Turin (44.9%), Trento (35.2%), Milan (30.6%), Genoa (22.2%).	Conti et al., 2004
Bologna, Milan, Rome, Turin	2003	Increase by 33% in Turin, 23% in Milan, 19% in Rome, 14% in Bologna, with highest impacts in age groups 75 to 84 years and over 85 years.	Michelozzi et al., 2005a
Milan, Rome, Turin	2003	Strongest impact in age group 75 to 84 years related to diseases of the central nervous system, cardiovascular, respiratory, metabolic diseases, psychological disorders and at low socioeconomic levels.	Michelozzi et al., 2005b
EuroHEAT project: nine European cities, including Milan and Rome	1987–2004	Increase among men: 24.7% in Rome, 37.3% in Milan; increase among women: 32.2% in Rome, 40.9% in Milan. The effect was stronger for intense heat-waves and for those of a long duration.	Michelozzi et al., 2007

Concerning heat waves, early warning systems and service assurance are the main areas where adaptation activities should be focused. Italy implemented within cities an early warning system for heat waves in 2003. The system enables a prediction of extreme weather events like heat stress three days in advance. Furthermore the data is collected and by connecting it to the mortality rate it can be evaluated. Therefore heat waves could be identified afterwards and predictions about future morality during heat stresses could be done. The data recording could also support assessment which includes research and monitoring of climate change effects on human health. Unfortunately figures about implementing the early warning systems are not available. The expenditures are assumed to be mostly public.

For an efficient and quick adaptation to heat waves, it is necessary to develop a policy which enables the different institutions working properly together and informing the public. This will help to be better prepared for upcoming extreme events, concerning autonomous as well as planned adaptation measures.

Beside the general adaptation measures on public health services, emphasised by the cCASHh project, technical prevention like air ventilation, cooling and isolation should be taken. These can concern planned adaptation within public buildings or private measures. The amount of expenditures for private measures is difficult to estimate. Alberini and Chiabai (2005) make use of the willingness to pay (WTP) concept. This method has been used in environmental terms to figure out the ability to pay for a certain level of environmental standard. In this case, the WTP shows how much money the individuals are willing to pay for a mortality risk reduction. In detail they asked people to report their WTP for a risk reduction of dying for cardiovascular and respiratory causes. These diseases could be imputable to heat stresses. Then the individual WTP can be used to assess the value of statistical life (VSL), which is a statistical term for a reduction in the risk of dying. They estimate in their original study (Alberini and Chiabai 2004) for a person of average age (Italy 40.6) for a medium risk reduction with average income for median VSL 0.73 million € and for mean VSL 1.533 million €. The figures can be useful to value the mortality benefits of adaptation to heat-waves.

Flooding

The impacts of floods on human health are severe. In Italy, more than 300,000 people were affected by flood events in 2003 (WHO 2007). Floods can cause at once an increase of the death rate. Italy especially, with a coastline of 7,400 km, is vulnerable to floods. The WHO (2007) claims that 4,200 km of coastal areas are at risk. Therefore, half of the Italian population would be affected directly or indirectly. In general, the adaptation strategy is strongly connected to coastal protection. The implementation of early warning systems as well as the land and coastal protection are the main planned adaptation methods. As already mentioned in the section about water (see section 6.3.1), the costs are mainly paid by the public sector (see Table 25 on page 123).

Vector-borne diseases

Due to its geographical position, the WHO (2007) calls Italy the “ideal bridge to the African continent”. Furthermore increasing temperatures provide ideal conditions for most of the vector-borne diseases. These two main circumstances – location and climate – are responsible drivers for vector-borne disease. The location of Italy is given and the temperature increase is projected, therefore Italy is one of European’s countries with special risk on vector-borne diseases for the future. Besides the location and changing in temperature the quality of the public health infrastructure is substantial.

According to WHO (2007) diseases with the highest risk level in Italy are visceral leishmaniasis and boutonneuse fever. The vector of visceral leishmaniasis is the sandfly. Nowadays about 500 cases per year are recorded, which mainly occur in the centre and the south of Italy (WHO 2007). The spreading into northern areas is expected when temperature increases. The boutonneuse fever is a bacterium infection which is communicated by ticks.

The round 1,000 cases a year are mainly recorded in central or southern Italy (WHO 2007). The WHO (2007) assesses the risk level of a movement towards northern parts as high. Other serious diseases are projected as moderate or low risky. One of them is malaria – a life threatening disease which is transmitted via bites of infected mosquitoes. About 700 cases per year are notified, but these are only imported once. The risk level for Italy is although low, but particular regions in the south and the islands could face future danger especially with increasing temperatures.

The private adaptation methods are mainly indoor residual protection and the avoidance of risk areas. Public adaptation includes providing information and prompt effective treatment, implementing monitoring systems and research of climate change related diseases as well as drug resistance.

Public and private adaptation measures concerning human health are basically the same as in Germany (see Table 8 on page 69).

6.4. The fiscal effects of adaptation

As with the case studies of Germany and Finland, for Italy, the quantitative research on adaptation costs in general and especially predictions about the extension of future fiscal burden, is rare. Furthermore, in the case of Italy the high social and economic inequalities across the country's regions might also force the government to act. This circumstance should be kept in mind, when looking at the adaptation costs. However, the last section provided an insight about the dimension of the public share within the different economic sectors.

The main threat of climate change to Italy is caused by sea level rise. Especially as a peninsula the country is under high pressure from this climate change impact. The adaptation to sea level rise is generally a public issue (see IMF 2008). This includes planned development within coastal areas as well as hard protection. The highest amount of public spending is due to dike buildings to protect Italian cities. These expenditures are expected to be the lion's share not only for the specific impact sea level rise but also within the overall adaptation measures. The private adaptation in case of sea level rise will be quite low in terms of costs.

The agriculture sector in Italy has only a small share in the economy and the production is specialised on cultivation particularly olives, wine and citriculture. The presented differentiation into short-term and long-term adjustments gives a rough estimation about the sharing of public and private adaptation costs. The short-term adaptation is assessed to be autonomous and therefore privately taken, whereas long-term adaptation, which means structural changes and developing an adaptation strategy, is mainly a governmental issue. As in the case of Finland already mentioned the overall public costs are expected to be at a relatively low level.

The tourism sector in Italy could be distinguished into coastal and alpine tourism. The coastal areas as summer destinations will be affected by hot summers as well as the danger of sea level rise. Besides giving a normative framework for construction design, the adaptation to hot summer is privately taken. Coastal protection is mainly a public issue as already mentioned and taken into account before. In case of winter tourism there is also expected that the adaptation costs are mainly private. An exception is public subsidies for investments into artificial snow making facilities. This kind of financial support is however not national regulated and differs from each province. Therefore no specific national projection for fiscal expenditures in that case can be given, but it seems that governmental support for operators is an important issue to maintain the regional tourism economy in the future.

The main threats of climate change to the health of Italians are heat waves, especially within cities. Therefore the implementation of early warning systems and providing the institutions with adequate infrastructure to work together are the main steps in the health sector to adapt to climate change. These measures are assumed to be mostly public, but figures about that are not available.

To summarise the projection of direct fiscal effects for Italy, one can say that the highest fiscal pressure and expenditures will occur due to sea level rise. The public costs to protect the Italian coasts are already on a high level especially with the project seeking to safeguard Venice. Within the other sectors, the public shares are not expected to be very high. However, especially given the potential impacts on the tourism sector, governmental pressure could result because of their possible indirect effects.

7. Knowledge Gaps in the case studies, Adaptation Costs matrix

In this section, together with the adaptation cost matrix we compile the quantitative results from the three country case studies in a more structured and comparable manner. Thereby we also show research foci and knowledge gaps and present the current state of research with regard to adaptation costs in Europe.

Adaptation to climate change is becoming increasingly prominent in the climate research agenda. Studies focussing on the vulnerability to climate change mostly incorporate adaptation needs and often stress the case for a proactive, precautionary climate policy which includes adaptation. Other topics of interest are the interdependency of mitigation and adaptation, adaptation constraints, and how to finance adaptation in developing countries. However, although most scholars propose a cost-benefit-approach to find the optimal adaptation path, the knowledge of concrete adaptation costs is limited because the costs of adaptation hinge on a lot of unknown parameters.

The same holds for adaptation costs in the European Union. There are plenty of (case) studies and project reports concerning adaptation to climate change, but very few provide estimates of the costs of proposed adaptation measures. The presented matrix composes adaptation cost estimates which are available for three representative EU member countries – Germany, Finland and Italy. These estimates are mostly extracted from bottom-up studies. In addition, it encompasses some cost estimates for the European level coming from top-down studies.

It should be stated that almost all data and estimates are just direct adaptation costs, which do not include indirect costs resulting from forgone profits or feedback effects on consumption due to altered investment and consumption behaviour (opportunity costs). Only very few studies try to give an insight into these effects, for example Bosello et al. (2006) through a CGE approach. These indirect effects might be considerable in many cases, in particular when studying the fiscal effects of adaptation. Indirect fiscal effects occur if public or private adaptation activities result in altered (mostly reduced) tax revenues. Bräuer et al. (2009) estimate these indirect fiscal effects of climate change for Germany by a Monte-Carlo-simulation and come to the conclusion that indirect fiscal effects far exceed the direct fiscal effects. The same can be expected for the indirect fiscal effects of adaptation measures. Unfortunately, the current state of research does not allow a reasonable statement concerning indirect effects (and fiscal indirect effects). So we are forced to focus on direct adaptation costs which result from the simple investment or maintenance costs and the public share of these costs. This constraint must be kept in mind when interpreting the overall fiscal effects of adaptation.

Another important knowledge gap is the allocation of adaptation costs between different public actors on different governmental levels. This is an issue highly relevant for a detailed projection of fiscal pressure due to adaptation. However, the literature hardly provides us with reliable total cost estimates – a reasonable literature-led analysis of cost allocation across different governmental levels is therefore not yet feasible and must remain an issue for future research.

7.1. The sources of data

The primary studies are listed in the references. Most are research project reports by national and supranational institutions. The ratio of peer-reviewed literature is extremely small; indeed there are only four peer-reviewed sources which provide quantified adaptation costs (i.e. Costa et al. 2009, Fischer et al. 2007, Bosello et al. 2006, and Tol 2002). As that number is so small, one cannot derive a significant tendency of an eventual difference between grey literature and peer-reviewed literature regarding the cost estimates. What can be said, though, is that there is no single peer-reviewed document focussing on other adaptation costs than coastal protection, agriculture or energy demand. For all the other impact areas only grey literature is available.

7.2. Description of the matrix and first results

7.2.1. Regional coverage

The first column of the matrix indicates the region for which the costs are estimated. Note that for the European adaptation costs some studies refer to total Europe, some to the EU in a specific composition and others to the European OECD countries. Particularly problematic are the figures for Eastern Europe and the Former Soviet Union, as only a small and unknown part of these figures are attributable to current EU member states. Interpreting the entries of the matrix, this has to be kept in mind.

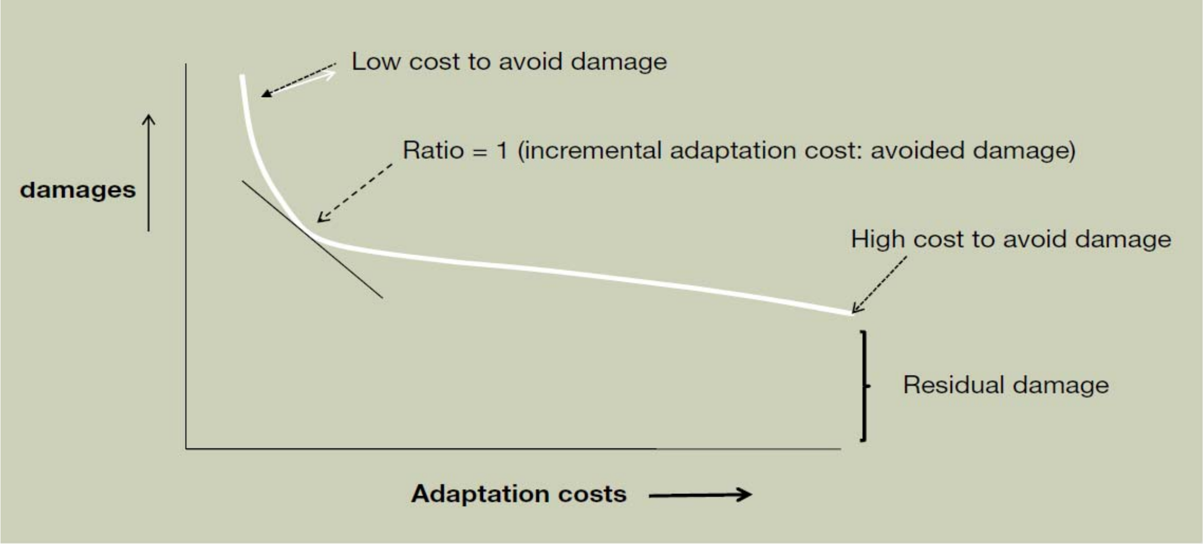
7.2.2. Scenarios

In the second column, the climate scenarios and socio-economic scenarios which form the basis for any calculation or estimation are named. This information is particularly important to classify the subsequent results and to get an insight whether they are rather optimistic or more pessimistic. Moreover, studies with identical regional coverage and scenarios, time spans and methodologies can be compared in their results. Unfortunately, the inadequate data hardly provides us with more than one comparable country-specific study. Nevertheless, as knowledge about adaptation costs is evolving, one could think of gradually filling the numerous gaps in the matrix. This is possible only under the condition that the development of climate science does not lead to significantly new scenarios, because then results would again lose their direct comparability.

Beside the scenarios regarding climate and socio-economic developments, adaptation scenarios are of great relevance. For example, there is a fundamental difference between the assumption of "total protection" of the current shoreline (i.e. protecting the land from every possible storm surge) and the assumption of "optimal coastal protection", which would incorporate the costs of protection into the decision. In the latter case the abandonment of highly endangered areas will be the consequence and the total costs will be less than in the former case. In the real world, there is often the policy of setting a certain protection level, since the realisation of optimal protection is not always practicable due to a lack of relevant data. A protection level of, say 1:400 means that the protection structures are designed to stand an event which statistically occurs just every 400 years. By setting these lump-sum protection levels the policy-maker avoids extensive cost-benefit-calculations for each and every coastal site. For the magnitude of adaptation costs, these adaptation decisions are of course crucial and every policy change significantly changes the involved costs.

Figure 39 depicts the theoretical background of that relationship. The exact curve is site-, sector- and time-specific, but the main character of adaptation costs will apply to most, if not all, situations. If adaptation policy focuses on high protection (i.e. lowers the damages), the adaptation costs will increase at an increasing rate. The economically optimal adaptation would be up to that point where the incremental adaptation costs equal the marginal avoided damage. More realistically, adaptation may be limited by a given budget constraint (for example the UNFCCC Adaptation Fund for the developing world).

Figure 39: Schematic of adaptation costs, avoided damages and residual damage. Source: Parry et al. 2009.



7.2.3. *Methodology and models*

The meaning of methods was already mentioned, so they are indicated in the third column. If a specific model was used and named in the literature, this is also being named here. In this column a first difference of bottom-up and top-down studies becomes apparent: Whereas the European (top-down) studies and predominantly based on extensive literature reviews or reasonable cost estimates, the country-specific (bottom-up) literature naturally is dominated by detailed case studies, some of them covering only small parts of the country.

7.2.4. *Time coverage and annualisation*

Sometimes the cost estimates are calculated for only one year in the future, e.g. 2050, and sometimes they are estimated for a series of consecutive years, e.g. the annual value will occur every year between 2020 and 2030. Hence, the year (respectively period) is indicated in the fourth column. This is important as one cannot assume the same cost structure or magnitude of costs during one century. Indeed, by comparing estimates from similar studies with different time horizons, one can find an increase in expected adaptation costs over time. This is not surprising as climate damages are increasing over time, which also induces higher adaptation needs. The only exception is the cost estimate of coastal protection in the European Union, assuming a very low sea-level rise of 9 cm by 2100 (PESETA 2009). This might be due to relatively high investments in early years, making additional investments in the second half of the century less important as the sea-level hardly rises in this scenario. It should be noted in this respect, that to date most projections have underestimated the sea-level rise and that a projected sea-level rise of 9 cm by 2100 clearly is an outlier in the current literature. Hence it might be questionable to choose this low value for a cost estimate.

Few sources give detailed information on annual costs for a given time period. One of them is Policy Research Corporation (2009), which names the scheduled expenditures for coastal protection by reviewing national and regional master plans up to 2015. In these cases we only give the average annual costs. As long as the annual amounts do not differ considerably, this is reasonable – in the other cases we have indicated the exact annual costs.

For reasons of comparability we calculated annual costs if costs are given for a time period longer than one year. That is, numbers that are calculated for a period of N years are divided by N to get the annual costs. This implies basically two simplifying assumptions: Firstly, adaptation costs are assumed to be constant over time. In reality, one can expect increasing adaptation costs over time (see above); but as no information about the exact distribution is given we choose the equal distribution. Secondly, we ignore inflation. The presented data are in prices of 2005 and therefore do not reflect price changes over time. The simple division by N does not, however, assume a discount rate of zero. The matrix just gives the estimated adaptation costs which may occur at a future point of time. It does not calculate these future costs in present values – only in this case discounting would become relevant.

After all, the matrix cannot provide a detailed budget-like expenditure plan for adaptation in the coming decades. It can just serve as a first rough insight into expected costs, partly based on best-guess-results.

7.2.5. The division into impact sectors

The presented adaptation costs are partitioned into different impact fields, as most adaptation measures are to reduce damages in specific sectors and can therefore be assigned to these sectors. In great parts the division into impact fields follows the three country case studies. One exception is the forestry sector: For this sector no concrete numbers of adaptation costs were available, consequently the sector was left out of the matrix.

A sector which is not explicitly analysed in the case studies is the cross section sector “Weather Extremes”. The literature cited in the matrix refers primarily to costs arising from adaptation of the constructed infrastructure, i.e. making the structures resilient to extreme weather events. These are costs which are hardly attributable to any impact sector. At the same time, they are quite high, e.g. up to an annual value of 50.9 billion € in the 2060s for Western Europe (Bosello et al. 2009).

By the partition into different impact sectors, the matrix provides a first insight into the current state of research of adaptation costs. It becomes clear that to date most cost estimates refer to coastal protection. It should not be implied, however, that this is the sector with the highest costs. It is just saying that here the impacts and adaptation techniques are quite well studied and the costs are well known, given an assumption for the future sea-level rise. In fact, the global adaptation cost study of UNFCCC (2007) estimates the costs of coastal protection in 2030 at a relatively low level. Adaptation in other fields like agriculture, forestry, fisheries, ecosystems, and – most outstanding – infrastructure will be much costlier, according to this source. However, these estimates come with a high level of uncertainty, whereas the knowledge of coastal protection costs is relatively well developed. On the other side, by comparing the sector-specific entries of coastal protection one can see a wide range of results even in that best-established research field. For great parts the differences can be reasoned by different assumptions regarding the sea-level rise or protection level, which is then indicated in the "Scenario" column.

The last column named "Total" contains results of studies which do not focus on specific sectors, but on the total impact of adaptation costs on the social welfare. There are only very few studies available which try to aggregate adaptation costs throughout the total economy. In principal, one can also sum up the entries of one line in the matrix to calculate the direct costs of adaptation in the analysed sectors and thereby yielding an approximate value for total direct adaptation costs in the economy. A prerequisite of that addition would be the use of identical scenarios, regional and time coverage and methods. Thus, the data actually does not allow a reasonable addition of single values due to a lack of comparable results. Note that additional indirect effects mentioned in the introductory section are completely left out of the picture if one just adds up the different sector impacts.

7.2.6. Exchange rates and inflation

The numerical entries in the matrix are – if not indicated otherwise – annual adaptation costs in million €, in the prices of 2005, and thereby comparable in terms of currency and price levels. The column named "Exchange and inflation" gives the original value found in the primary literature and the calculation to € in prices of 2005.

For the translation of USD into € we used the average market exchange rate of the year of the respective study.

In a second step, we adjusted for price level changes. E.g., the construction of a dike in the year 2000 will be more expensive than the same dike constructed in 1990. To make both estimates comparable, we used price indices to standardise all figures to prices of 2005. For capital-intensive adaptation in specific country studies it appears reasonable to apply national price indices for capital formation. For not sufficiently concretised adaptation measures we used the national GDP price indices. For studies with European coverage we applied equivalent price indices for the €-area as an approximation for the price level changes in the studied area.

7.3. The Matrix

Country	Scenario	Methodology / Model	Year	Entries	Agriculture	Water supply	Inland floods	Coastal floods	Health	Tourism	Energy	Transport	Weather Extremes	Total	Exchange and inflation
					million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	in millions
Germany	past data	Econometric study of past data	1985-2007	Costs									no significant influence on public budgets		
				Source									Lis and Nickel 2009		
	past data	Review of past expenditure	2008-2009	Costs						65 (only artificial snow)					No information about price level
				Source						alpMedia 2004					
	SLR: 15-50 cm by 2100; Protection level: 1:100 to 1:400	Review of scheduled expenditure	1998-2015	Costs				143 (not only due to climate change)							No information about price level
				Source				Policy Research Corporation 2009							
	SLR: 70 cm, maintain current protection level	Case study	n.a.	Costs				46 (one-time investment, only Lower Weser river)							87.75 2000DM = 44.9 2000€ = 45.7 2005€
				Source				Liebermann and Zimmermann 2000							
		Case study	n.a.	Costs				31 (one-time investment, only 4 focus points at the North Sea, total dike length 85.2 km)							No information about price level
				Source				Mai et al. 2004							
	SLR: 1 m by 2100	Case study, expert opinion	2050	Costs				23							25 2007€ = 22.8 2005€
				Source				Bräuer et al. 2009							
	SLR: 1 m by 2100	Case study, expert opinion	2100	Costs				91							
				Source				Bräuer et al. 2009							
	SLR: 50 cm by 2050	Case study	2050	Costs				+ 75% (only Wadden Sea)							
				Source				CWSS 2001							
	n.a.	Case study, rough estimates	2050-2100	Costs		37-711									40 2007€ = 36.5 2005€
				Source		Bräuer et al. 2009									

Country	Scenario	Methodo-logy / Model	Year	Entries	Agriculture	Water supply	Inland floods	Coastal floods	Health	Tourism	Energy	Transport	Weather Extremes	Total	Exchange and inflation
					million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	in millions
	A2	Forecast of heating degree days, estimates	2100	Costs							-4863 (less energy demand)				5000 2007€ = 4862.8 2005€
				Source							Bräuer et al. 2009				
	B2	Case study	2050	Costs	1.2-7.5 (only fruit sector in Hesse)										No information about price level
				Source	HLUG 2005										
	T: 4,5°C by 2100	WIAGEM Model	2050	Costs	116				552	220		235*)			No information about price level
				Source	Kemfert 2007				Kemfert 2007	Kemfert 2007		Kemfert 2007			
	T: 4,5°C by 2100	WIAGEM Model	2100	Costs	480				2332			976*)			No information about price level
				Source	Kemfert 2007				Kemfert 2007			Kemfert 2007			
	A2, SLR: relatively 50-100 cm by 2100, protection level: 100 years event	DIVA Model	2000-2100	Costs				17.3							0.099346% of 2007GDP for 100 years; 0,000993% of 2007GDP for 1 year = 28.68 2008USD = 19.60 2008€ = 17.31 2005€
				Source				Costa et al. 2009							
Finland	past data	Econometric study of past data	1985-2007	Costs									no significant influence on public budgets		
				Source									Lis and Nickel 2009		
	A1T	Estimates based on literature review	2020	Costs			<11				1.1 (only maintenance)				1 2000€ = 1.093 2005€
				Source			Perrels et al. 2005				Perrels et al. 2005				
	A1T	Estimates based on literature review	2050	Costs			<11				1.1 (only maintenance)				
				Source			Perrels et al. 2005				Perrels et al. 2005				
	A1T	Estimates based on literature review	2080	Costs			<11				1.1 (only maintenance)				
				Source			Perrels et al. 2005				Perrels et al. 2005				

Country	Scenario	Methodology / Model	Year	Entries	Agriculture	Water supply	Inland floods	Coastal floods	Health	Tourism	Energy	Transport	Weather Extremes	Total	Exchange and inflation
					million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	in millions
	Larger future floods	Estimates based on literature review	2070	Costs			0.005-7 (initial investment)	1-10 (initial investment, only Pori)							No information about price level
				Source			Silander et al. 2006	Silander et al. 2006							
	SLR: 60 cm, maintain current protection level	Review of scheduled expenditure	1998-2015	Costs				0.45							No information about price level
				Source				Policy Research Corporation 2009							
	n.a.	Simulation, Estimates based on literature review	2030	Costs							-2% (less energy demand)	10-20 (buildings and transport infrastructure)			No information about price level
				Source							Kirkinen et al. 2005	Carter et al. 2007			
	A1B	Simulation, Estimates based on literature review	2100	Costs							-4.5% (less residential electricity demand)	>20 (buildings and transport infrastructure)			No information about price level
				Source							Eskeland and Mideksa 2009	Carter et al. 2007			
	A2, SLR: relatively 50-100 cm by 2100, protection level: 100 years event	DIVA Model	2000-2100	Costs				5.15							0.422518% of 2007GDP for 100 years; 0,00422518% of 2007GDP for 1 year = 8.13 2008USD = 5.55 2008€ = 5.15 2005€
				Source				Costa et al. 2009							
Italy	VSL (Value of a statistical Life) median WTP Risk Reduction to die on health effects of heat waves	survey	2005	Costs					0.73						No information about price level
				Source					Alberini and Chiabai 2005						
	VSL (Value of a statistical Life) mean WTP	survey	2005	Costs					1.533						
				Source					Alberini and Chiabai 2005						

Country	Scenario	Methodo-logy / Model	Year	Entries	Agriculture	Water supply	Inland floods	Coastal floods	Health	Tourism	Energy	Transport	Weather Extremes	Total	Exchange and inflation
					million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	in millions
🟥	Risk Reduction to die on effects of heat waves														
	Discount rate 3.5	Case study	2030	Costs				1.5-2.1 (in 2030) only Venice but without MOSE							No information about price level
				Source				Carraro and Sgobbi 2008							
	n.a.	Review of scheduled expenditure	2009-2015	Costs				790.8 (in 2009-2011, including MOSE project) 23.30 (in 2012-2015, MOSE project completed)							No information about price level
				Source				Policy Research Corporation 2009							
	n.a.	expenditure forecast for MOSE project	n.a.	Costs				4680 total for MOSE project (no time horizon)							No information about price level
				Source				Ministry for Infrastructure and Transport 2009							
	A2, SLR: relatively 50-100 cm by 2100, protection level: 100 years event	DIVA Model	2000-2100	Costs				26.9							0.23037% of 2007GDP for 100 years; 0,0023037% of 2007GDP for 1 year = 42.5 2008USD = 29.04 2008€ = 26.93 2005€
				Source				Costa et al. 2009							

Country	Scenario	Methodo-logy / Model	Year	Entries	Agriculture	Water supply	Inland floods	Coastal floods	Health	Tourism	Energy	Transport	Weather Extremes	Total	Exchange and inflation
					million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	in millions
EU	SLR: 25 cm, total protection	Global CGE, 8 regions	2050	Costs				281						0.022% of GDP (indirect effects through investments in coastal protection)	11213 1997USD = 9921.5 1997ECU = 11254.3 2005€ for time span by 2050 (assumed period 2010-2050 = 40 years)
				Source				Bosello et al. 2006						Bosello et al. 2006	
EU27	A2, SLR: 88 cm by 2100, optimal protection		2020-2029	Costs				1172							1013.4 1995€ = 1171.9 2005€
			2080-2089	Costs				3016							
				Source				PESETA Final Report 2009							
	B2, SLR: 9 cm by 2100, optimal protection		2020-2029	Costs				352							
			2080-2089	Costs				314							
				Source				PESETA Final Report 2009							

Country	Scenario	Methodology / Model	Year	Entries	Agriculture	Water supply	Inland floods	Coastal floods	Health	Tourism	Energy	Transport	Weather Extremes	Total	Exchange and inflation
					million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	in millions
Western Europe	A2r (population growth lower than A2)	Climate model Hadley, agriculture model AEZ-BLS, cost estimates	2030	Costs	966 (only irrigation)										no information about price level, assuming price level of 2005: 30 Gm³ * 0.04 2005USD/m³ = 1200 2005USD = 965.3 2005€
			2050	Costs	1544 (only irrigation)										
			2080	Costs	2702 (only irrigation)										
				Source	Fischer et al. 2007										
	B1		2030	Costs	290 (only irrigation)										
			2050	Costs	450 (only irrigation)										
			2080	Costs	547 (only irrigation)										
				Source	Fischer et al. 2007										
	A2r (population growth lower than A2)	Climate model CSIRO, agriculture model AEZ-BLS, cost estimates	2030	Costs	161 (only irrigation)										
			2050	Costs	322 (only irrigation)										
			2080	Costs	611 (only irrigation)										
				Source	Fischer et al. 2007										
	B1		2030	Costs	225 (only irrigation)										
			2050	Costs	290 (only irrigation)										
			2080	Costs	386 (only irrigation)										
				Source	Fischer et al. 2007										
Western Europe	2x CO2, T = 2.5°C, SLR: 44 cm	AD-WITCH, CGE ICES, cost estimates	2060-2065	Costs	6274 (only irrigation)	2655		4022	-563		1935		50919	67248	7800 2005USD = 6274 2005€
				Source	Bosello et al. 2009	Bosello et al. 2009		Bosello et al. 2009	Bosello et al. 2009		Bosello et al. 2009		Bosello et al. 2009	Bosello et al. 2009	
Eastern Europe				Costs	9894 (only irrigation)	4263		241	-80		0		1931	16329	
				Source	Bosello et al. 2009	Bosello et al. 2009		Bosello et al. 2009	Bosello et al. 2009		Bosello et al. 2009		Bosello et al. 2009	Bosello et al. 2009	

Country	Scenario	Methodology / Model	Year	Entries	Agriculture	Water supply	Inland floods	Coastal floods	Health	Tourism	Energy	Transport	Weather Extremes	Total	Exchange and inflation
					million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	in millions
Europe	AD-RICE (emissions < B2, T = 2°C by 2100)	Global CGE, 13 regions, optimal adaptation and mitigation	by 2155	Costs										NPV of annual flows = 0.06% of NPV GDP	NPV of annual flows, no price level
				Source										de Bruin et al. 2009	
EU27 + Norway + Switzer-land	4°C warming by 2100	Partial Equilibrium models	2020	Costs							-6941 (less energy demand) + 4300 (additional cooling investments)				No information about price level
			2035	Costs							-15602 (less energy demand) + 6200 (additional cooling investments)				
			2050	Costs							-27663 (less energy demand) + 8400 (additional cooling investments) + 1000 (additional investments in power plant cooling measures)	3000-6000 (only infrastructure)			
				Source							Jochem and Schade 2009	Jochem and Schade 2009			

Country	Scenario	Methodo-logy / Model	Year	Entries	Agriculture	Water supply	Inland floods	Coastal floods	Health	Tourism	Energy	Transport	Weather Extremes	Total	Exchange and inflation
					million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	in millions
OECD Europe	A1B, SLR: 9 cm by 2030	Estimates based on literature review	2030	Costs		875		593					804 - 13715		87000 2005USD for investment by 2030, 25% for adaptation 21750 2005USD = 17496 2005€ for time span, 875 2005€ as annual costs
				Source		UNFCCC 2007		UNFCCC 2007					UNFCCC 2007		
	B1, SLR: 9 cm by 2030	Estimates based on literature review	2030	Costs		251		502					804 - 13715		
				Source		UNFCCC 2007		UNFCCC 2007					UNFCCC 2007		
	SLR: 1 m by 2100	Estimates based on literature review	2000-2100	Costs				1612							No information about price level, assuming price level of 2000: 136000 2000USD = 147516.5 2000€ = 161238.3 2005€, original results for period of 100 years
				Source				Tol 2002							
	T: 1°C	Estimates based on literature review	n.a.	Costs					no adaptation costs for diarrhea, malnutrion and malaria		6350 (additional cooling demand, saved heating expenditure)				No information about price level, assuming price level of 1995: 7100 1995USD = 5451.4 1995ECU = 6350.2 2005€
				Source					Tol and Dowlatabadi 2001		Tol 2002				

Country	Scenario	Methodology / Model	Year	Entries	Agriculture	Water supply	Inland floods	Coastal floods	Health	Tourism	Energy	Transport	Weather Extremes	Total	Exchange and inflation
					million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	million 2005€ p.a.	in millions
Eastern Europe and FSU	NCAR (wet)	Estimates based on literature review	2010-2019	Costs									1210		1 2005USD = 0.8044 2005€
			2020-2029	Costs									1530		
			2030-2039	Costs									3540		
			2040-2049	Costs									4260		
				Source									World Bank 2009		
	CSIRO (dry)		2010-2019	Costs									563		
			2020-2029	Costs									885		
			2030-2039	Costs									1210		
			2040-2049	Costs									1690		
				Source									World Bank 2009		
	NCAR (wet)		2010-2050	Costs	80 (research) 80 (irrigation)	80 (only infrastructure) + 724	1125		563 (only infrastructure)		483 (only infrastructure)	804 (only infrastructure)			
				Source	World Bank 2009	World Bank 2009	World Bank 2009		World Bank 2009		World Bank 2009	World Bank 2009			
	CSIRO (dry)		2010-2050	Costs	80 (research) 80 (irrigation)	-241	483								
				Source	World Bank 2009	World Bank 2009	World Bank 2009								
	SLR: 87,2 cm by 2100		2010-2019	Costs				1930							
			2020-2029	Costs				2090							
			2030-2039	Costs				2250							
			2040-2049	Costs				2490							
				Source				World Bank 2009							

Country	Scenario	Methodology / Model	Year	Entries	Agriculture	Water supply	Inland floods	Coastal floods	Health	Tourism	Energy	Transport	Weather Extremes	Total	Exchange and inflation
					million 2005€ p.a.	**million 2005€ p.a.**	**million 2005€ p.a.**	**million 2005€ p.a.**	**million 2005€ p.a.**	**million 2005€ p.a.**	**million 2005€ p.a.**	**million 2005€ p.a.**	**million 2005€ p.a.**	**million 2005€ p.a.**	**in millions**
EC12 without GDR	SLR: 50 cm and T: 2,5°C by 2100	Partial Equilibrium	2000-2100	Costs				140			7014 (only additional electricity expenditures)				No information about price level, assuming price level = 1990: 140 1990USD = 110 1990ECU = 140 2005€
				Source				Fankhauser 1992			Fankhauser 1992				
Western Europe + Croatia, Cyprus, Slovenia	unmitigated IPCC IS92a scenario, medium estimate	Simulation, Estimates based on literature review	up to 2030	Costs					no adaptation costs for diarrhea, malnutrion and malaria						
				Source					Ebi 2007						

*) In the primary study costs are aggregated for the sectors business, industry and transport. Here we estimated the transport costs using the GDP share of the transport sector.

Meaning of colours:

Grey	Peer-reviewed studies
Green	Results from Case Study Germany
Yellow	Results from Case Study Finland
Red	Results from Case Study Italy
Blue	Results from Top-Down-Studies for different European aggregates

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